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RESIDENTIAL ENERGY ECOSYSTEM

Achieving Zero Carbon Lifestyle Through Solar Self-Consumption for an All Electric Household with an Electric Car in Catalonia

This master's thesis is submitted for the interuniversity

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Abstract

Environmentalists are pressing hard to limit the average global temperature rise in 2050 to well below 2°C, while pursuing efforts for a tougher ceiling of 1.5°C. While government policies may encourage the decarbonisation of industries, such ambitious transition towards renewable energy should not omit the participation of private consumers. Since solar energy for self-consumption is accessible to an average consumer, most will be able to use such solution to reap strategic and economic benefits while having greater energy security and more freedom to take energy decisions that suit them. As a consequence, this paper aims to design an economically feasible method of achieving zero carbon lifestyle in the context of residential energy ecosystem. Building on existing technologies, it asks: how can a private household adopt a zero carbon lifestyle that is affordable yet profitable? And how can solar self-consumption rates be increased without involving additional investment? First, an in-depth analysis of recent developments of the domestic electricity market in Catalonia, including an overview of the current technological marketing environment is presented. Second, a complete electrification process of the household which involves regular electric car charging is designed. Third, a user-centred energy management system driven by data to maximise savings is developed. To finish, a comparison with other existing solutions against this system is examined. The result has shown that although the system has not been able to triumph in terms of self-consumption rate, it has certainly outperformed the rest in terms of profitability.

Keywords: Zero Carbon, Energy Management, Solar Photovoltaic, Electric Car

Abstrak

Aktivis alam sekitar berusaha keras untuk membatasi kenaikan median suhu global pada tahun 2050 pada kadar maksima 2°C, sambil meneruskan usaha untuk mencapai siling yang lebih keras iaitu 1.5°C. Walaupun kebijaksanaan kerajaan dapat mendorong dekarbonisasi sektor industri, peralihan yang bercita-cita tinggi terhadap tenaga boleh diperbaharui tidak boleh mengabaikan penyertaan rakyat. Oleh kerana tenaga solar untuk penggunaan sendiri semakin murah, kebanyakan rakyat akan dapat menggunakan teknologi tersebut untuk meraih keuntungan strategik dan ekonomi sambil memiliki keselamatan sumber tenaga yang lebih tinggi dan lebih banyak kebebasan untuk mengambil keputusan mengenai penggunaan tenaga yang sesuai dengan mereka. Akibatnya, tesis ini bertujuan untuk merancang kaedah yang terbaik dari perspektif ekonomi untuk mencapai gaya hidup sifar karbon dalam konteks ekosistem tenaga domestik. Berdasarkan teknologi terkini, ia mengungkap persoalan berikut: bagaimana sebuah rumah dapat menikmati gaya hidup sifar karbon dengan harga yang berpatutan, malah menguntungkan? Dan bagaimana kadar penggunaan sendiri dapat dinaikkan tanpa melibatkan pelaburan tambahan? Pertama, analisis mendalam mengenai perkembangan terkini pasaran elektrik domestik, termasuk gambaran keseluruhan persekitaran pemasaran teknologi semasa akan dibentangkan. Kedua, proses elektrifikasi lengkap isi rumah yang melibatkan pengecasan kereta elektrik akan dirangkakan. Ketiga, sistem pengurusan tenaga berpusat pada pengguna yang didorong oleh data untuk memaksimumkan penjimatan akan dibangunkan. Sebagai penutup, perbandingan dengan penyelesaian lain yang ada berbanding dengan sistem ini akan diperiksa. Keputusan telah menunjukkan bahawa walaupun sistem ini tidak dapat menang dari segi kadar penggunaan sendiri, ia telah berjaya mengatasi penyelesaian lain dari segi keuntungan.

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Interpretation

Abbreviation	Definition
A	Ampere, unit of Current
AC	Alternating Current
BEV	Battery Electric Vehicle
CNMC	*Comisión Nacional de los Mercados y la Competencia* National Commission for Markets and Competition
CO_2	Carbon Dioxide
DC	Direct Current
ESS	Energy Storage System
EU	European Union
EV	Electric Vehicle
FIT	Feed-in-Tariff
GHI	Global Horizontal Irradiance
ICAEN	*Instituto Catalán de Energía* Catalan Institute of Energy
IDAE	*Instituto de Diversificación y Ahorro Energético* Institute of Energy Diversification and Saving
IRENA	International Renewable Energy Agency
IVA	*Impuesto sobre Valor Añadido* Value Added Tax
PHEV	Plug-in Hybrid Electric Vehicle
PV	Solar Photovoltaic
PVPC	*Precio Voluntario al Pequeño Consumidor* Voluntary Price for the Small Consumer
RD	Royal Decree
UNEF	*Unión Española Fotovoltaica* Spanish Photovoltaic Union
V	Volt, unit of Voltage
W	Watt, unit of Power
Wh	Watt-hour, unit of Energy

1. Introduction

The historic Paris Agreement 2015 seeks, at minimum, to limit average global temperature rise to “well below 2°C” in the present century, compared to pre-industrial levels. Renewables, in combination with rapidly improving energy efficiency, form the cornerstone of a viable climate solution. Keeping the global temperature rise below 2°C is technically feasible. However, the global energy system must undergo a profound transformation, from one largely based on fossil fuels to one that enhances efficiency and is based on clean, sustainable and renewable energy. Such a global energy transformation – seen as the culmination of the energy transition that is already happening in many countries – must involve the residential and the private transportation sector. However, the question that keeps lingering in many citizen’s mind is; *how do I do it? Is it affordable?* And more importantly, *is it a profitable investment?*

This paper deals with the role of citizens in the context of the zero carbon energy transformation. Its purpose is twofold: first, to design a zero carbon energy ecosystem with solar self-consumption for an all-electric household with an electric car in the region of Catalonia. Second, to design a smart energy management system to maximise solar energy self-consumption from an economic perspective.

The energy ecosystem in this paper largely focuses on fulfilling the entire energy needs of a typical grid-connected private households in Catalonia with a small-scale PV system. It factors in regular electric usage plus heating, cooking, cooling, domestic hot water and electric car charging.

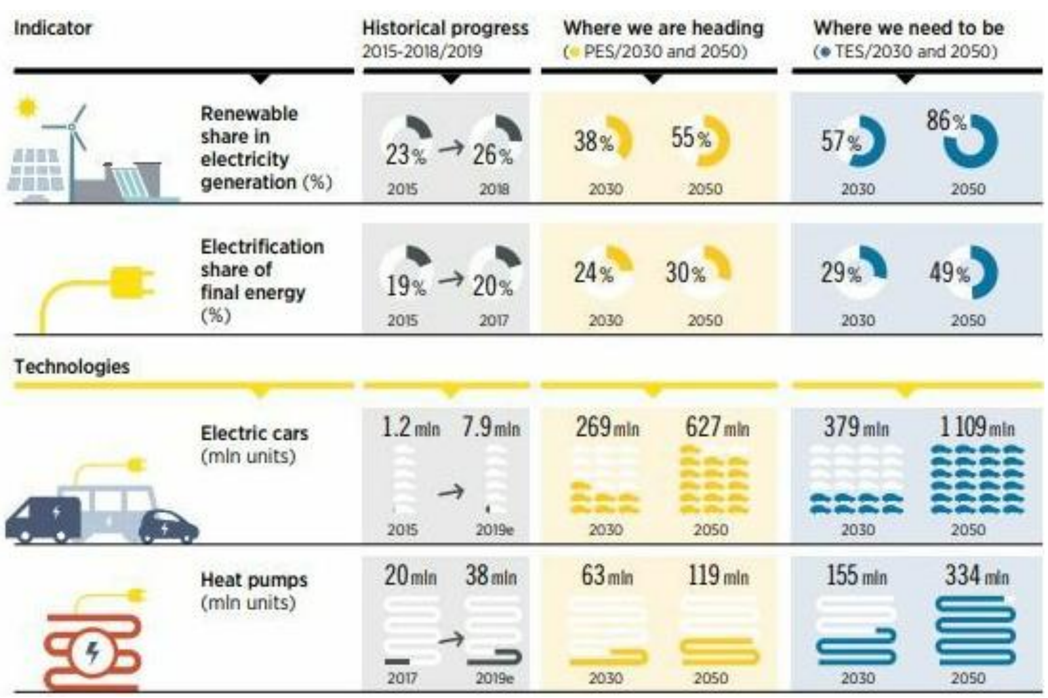
Spurred by technology development and regulatory frameworks, PV self-consumption of distributed renewable electricity generation has gained relevance in many households around the world. To be precise, PV self-consumption is defined as the act of using solar power to run electrical loads connected to the house. Adopting the role of a prosumer, any energy that the PV system produces will go first to power any devices that happen to be running – thus reducing the amount of energy the household has to purchase from the electricity retail company. This will happen automatically when loads are switched on while the PV system is producing energy. If the PV system produces more energy than the actual consumption at a given moment, the excess energy is automatically fed into the grid. This ‘exported’ solar energy is what earns the prosumer the feed-in tariff compensation – which is rather low when compared to what the prosumer pays for.

With energy storage, the self-consumption rate of an average Central European household running a PV system can go up to 65-75%. In absence of such flexibility measures, however, residential consumers are more likely to obtain self-consumption rates in the range of 20% to 30%. In the context of responsible energy usage, high self-consumption rates has therefore the potential to drive consumers' uptake of PV system as it corresponds to higher savings. Driven by innovation in data and design, the paper will also take a look at how can self-consumption rates be increased without involving additional investment, as consumers have an interest to increase their energy savings and reduce their exposure to volatile electricity prices.

2. The Low Carbon Energy Transformation Plan

2.1 The Paris Agreement, A Worldwide Transition to Clean Energy

A 2018 Global Energy Transformation report by IRENA shows that the current global emission trends are not on track to meet the 2℃ goal. Government plans still fall far short of emission reduction needs. Under current and planned policies, the world would exhaust its energy-related "carbon budget" in under 20 years to keep the global temperature rise to well below 2°C, while fossil fuels such as oil, natural gas and coal would continue to dominate the global energy mix for decades to come.



Picture 1: Worldwide Domestic Energy Usage Progress, 2018

To meet the 2°C goal, immediate action will be crucial. Renewable energy needs to be scaled up at least six times faster. Cumulative emissions must at least be reduced by a further 470 Gt by 2050 compared to current and planned policies to meet that goal.

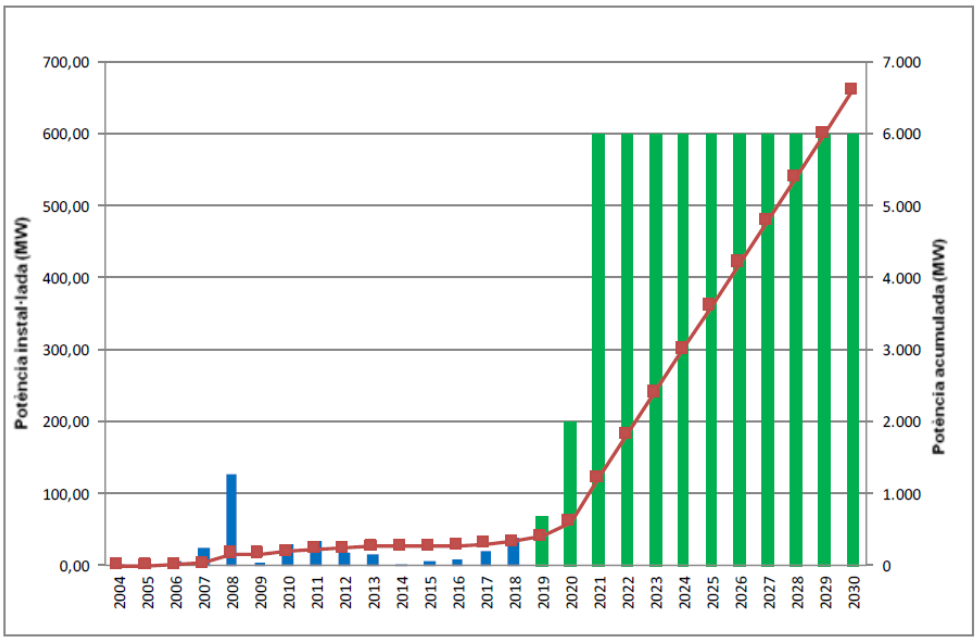
The EU energy consumption per capita as of April 2019 is well above the global average at 51 GJ per year. This is partially due to its very high fossil fuel net import as the region possesses very limited domestic fossil fuel resources compared to primary energy consumption; heavy dependence on imported oil (93% of oil supply) and gas (79% of gas supply). In addition, the region's annual emissions per capita as of 2018 was at 6.4 tCO_2. All of these alarming factors indicate an urgent contingency plan in order to achieve the 2°C goal, yet alone the 1.5°C.

In short, citizens should also play their role in this energy transformation. As per IRENA's suggestion, a citizen can achieve a zero carbon energy lifestyle by increasing their share of renewable energy, adoption of electromobility and usage of heat pumps.

2.2 The Integrated National Energy & Climate Plan, Spain's Answer to 2℃

The Plan Nacional Integrado de Energía y Clima 2021 – 2030 (Integrated National Energy and Climate Plan) has defined the objectives of reducing greenhouse gas emissions, penetration of renewable energy and energy efficiency. It is an effort consistent with an increase in the global energy transformation ambition at the European level by 2030, as well as with the Paris Agreement.

The framework seeks a 23% reduction in greenhouse gas emissions compared to 1990. This reduction objective involves eliminating one out of every three tons of greenhouse gases currently emitted. In the context of renewable energy, it foresees for the year 2030 that 74% of electricity generation will be through renewables. This implies a nationwide total installed power in the electricity sector of 161 GW of which 39 GW will be solar PV. In order to reach this target, UNEFCAT implies a minimum projection of 600 MW of solar PV commissioned every year in Catalonia alone.



Picture 2: Solar PV projection in Catalonia

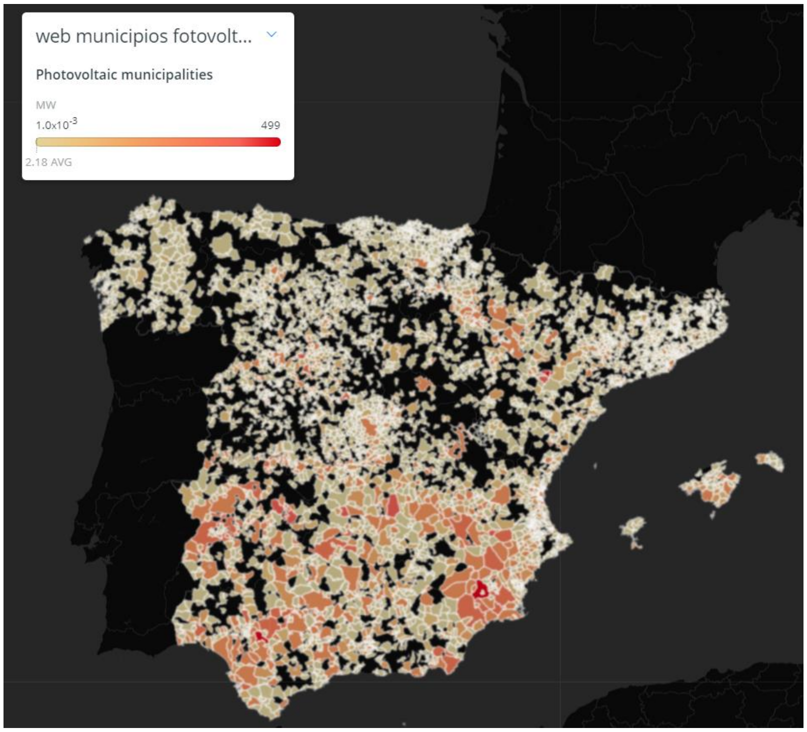
Regarding storage, note the rise in storage technologies with an additional power of 6 GW, providing greater renewable energy management. Together with the drive for flexibility and demand management, this will allow a greater integration of renewable generation in the system, contributing to security of supply.

Several of the measures introduced in this plan also involve a transformation of the energy system towards a more resilient model against climate change. The elaboration of this plan is, in this sense, one of the first steps aimed at building an adaptive capacity and providing actions for a better adaptation of the energy system.

The rest of the dimensions also include complementary measures that contribute to a better adaptation. Improving security of supply, less dependence on fossil fuels, together with measures dedicated to improving research and competitiveness in low-carbon technologies, contribute to the implementation of an energy system resilient to climate change.

2.3 Solarcat, Catalonia to Move Itself Forward

The development of solar PV for self-consumption in Catalonia has been significantly slower compared to other regions. The use of said renewable energy has always been mainly concentrated in the southern region of Spain such as Andalusia and Murcia. This is particularly due to lower solar radiation within the region, resulting in a lower energy yield.



Picture 3: Map of PV installations, July 2019

On 17 October 2017, the Government of Catalonia launched SOLARCAT, a strategy that will guarantee the capture and use of Catalonia's solar energy resource, and in particular, the electric use of solar PV, identifying and developing the necessary technical, economic, legal and socio-cultural instruments.

The strategy will set the specific strategic and numerical objectives, as well as the deadlines, for the development of solar PV in Catalonia for the coming years. The government of Catalonia will convene lines of economic incentive to promote the development of solar PV self-consumption in all sectors. A renewable energy model cannot be implemented without the private consumer leveraging its potential.

Solarcat also convenes on working on solutions to integrate renewable electric energy generation with the benefits of energy storage. It is understood that EVs are not only a more efficient mobility system, but also as a battery that must allow both the storage of surplus solar energy and intelligent energy management.

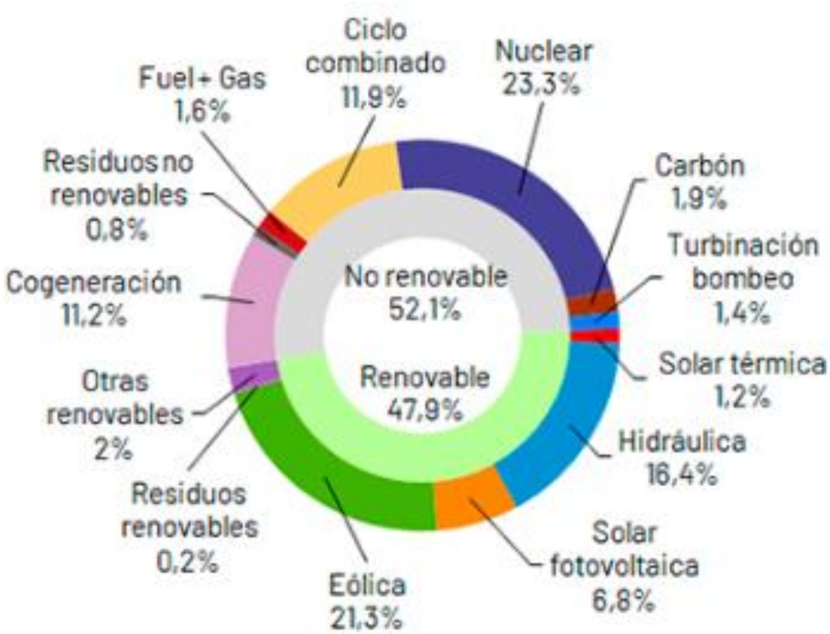
3. Feasibility Analysis

3.1 Environmental Perspective

Going full electric is claimed to be more environmentally friendly – though there are some stipulations to this. A domestic and private transport electrification will be as good as pointless if the electricity generation plants themselves cause pollution. As electrical energy is a clean energy source when it is used, it can be harmful to the environment when it is being produced. It should be recalled that according to a 2018 data from Red Eléctrica de España, each kWh of electricity generated produces 251 g of CO_2, meaning that an electric car that is charged by the grid has indirect average emissions of 37.75 grams of CO_2 per km.

Nevertheless, a successful implementation of decarbonisation of electricity has a promising potential for a significant reduction in CO_2 emissions, laying firm foundations to consolidate a climate neutrality trajectory of the economy and society in the 2050 horizon. Thus, grid decarbonisation is a key element that should be focused on.

Fast forward to the month of April 2020, 72.6% of the national electricity production came from technologies that do not emit CO_2. The share is made up of nuclear, pumped hydro, solar thermal, hydro, solar photovoltaic, wind and other renewables. A singularity that must be pointed out is that it is a full month that the country was under lockdown due to Covid-19.

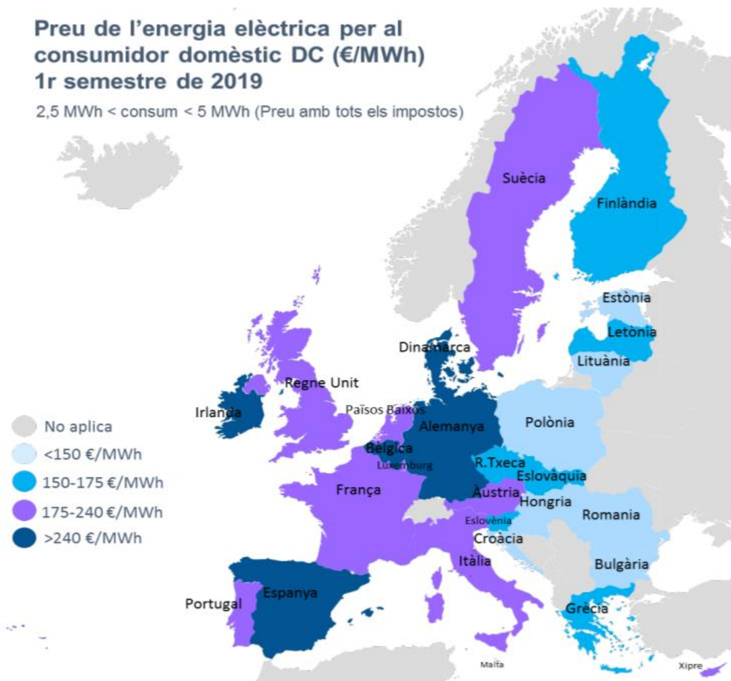


Picture 4: National Electricity Generation, April 2020

In Spain, the CNMC has defined 'green electricity' as electricity whose origin that has been generated through renewable sources. Thus, if a house buys their electrical energy from a company that uses renewable methods to generate electricity, then it will have a significantly lower effect on the environment. However, if it is produced in a coal plant then it can no longer be considered zero carbon.

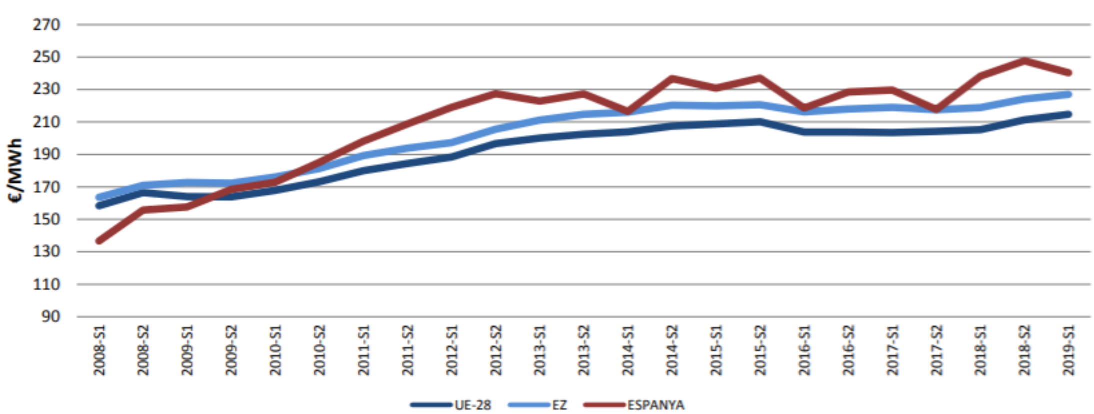
3.2 Economic Perspective

According to a 2019 comparative study of energy prices in Europe, a Spanish household with annual electricity consumption between 2500 kWh and 5000 kWh pays on average 11.9% more than a comparable household from another EU country. Data shows that Spain is among the top 5 countries with the most expensive electricity price in the EU.



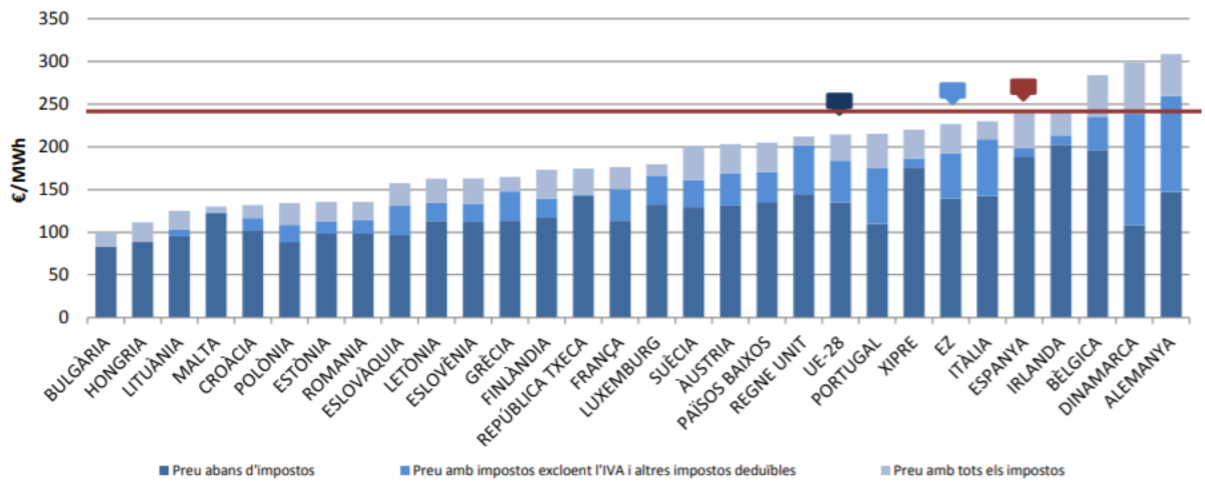
Picture 5: Electricity price for domestic consumer, 1st half of 2019

Between the year 2008 and 2019, the price of electricity in Spain for domestic consumers experienced a 76% increase. In the same period, the increase in the EU and the Eurozone is 36% and 39% respectively.



Picture 6: Semiannual evolution of tax prices between the EU, the Eurozone and Spain, 2008 – 2019

During the first half of 2019 the price in Spain continues to be above the EU average. Only in Ireland, Belgium, Denmark and Germany electricity is more expensive than in Spain.

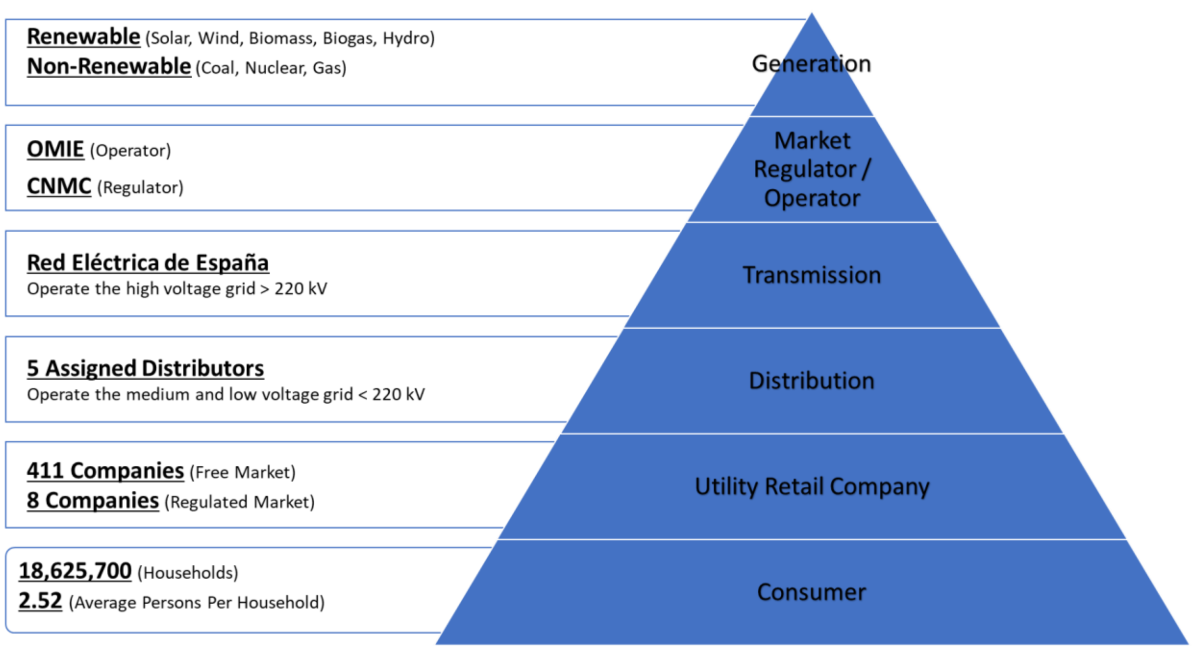


Picture 7: Electricity price comparison between the EU, Eurozone and Spain, 1st half of 2019

This is the biggest barrier to going full electric. Consumers are aware that they are paying too much for their electricity. Due to this factor, it is difficult to justify the move to own an all-electric household, let alone pairing it with an electric car. The obvious choice for many, is the more affordable option.

In addition to that, consumers are aware that the cheaper, fossil based energy source contributes to pollution. They are also aware that the national grid is not powered by 100% renewable energy, or even zero carbon energy resources. One might argue that it is the sole responsibility of the government to provide them with clean energy. Due to this, majority of the consumers are not ready to sacrifice their hard earned money in order to achieve the 2℃ goal. Hence, converting every single one of their household appliances into electricity plus owning an electric car is seen as an uphill battle.

Furthermore, the long list of stakeholders in the electricity market makes it nothing less than difficult to help reduce the retail price of electricity in the future.



Picture 8: Stakeholders of the electricity market

3.3 Legislation Perspective

On 5 October 2018, a new legislation was approved for self-consumption in Spain. The RD 15/2018 on urgent measures for energy transition and consumer protection has ended the RD 900/2015 which established type 1 and 2 of self-consumption and strongly limited their use and application.

Under the new legislation, one of the measures that radically changed self-consumption in Spain is the elimination of the "sun tax" (self-consumed energy that does not pass through the network is exempt from the network charge or toll). In addition to improving amortization times, this measure reduces the fear of self-consumption that had been engraved in the society, thus encouraging many consumers to consider self-consumption. The regulation also adopted measures to accelerate the energy transition to a model based on renewable energies. Among others, the activity of recharging EVs was made more flexible, eliminating the figure of the load manager. The legal text has set a fight against energy poverty, which affects some 4.6 million people, as a priority.

Improvement	RD 900/2015	RD 15/2018
Elimination of the sun tax	Transitional charge for self-consumed energy	Free renewable self-consumption of all types of charges and tolls
Simplifies technical requirements and administrative procedures	Smart meter	No obligation
	Access and connection procedures	Exempted: without excess or until 15 kW
	100 kW limit	The limit of the contracted power is also eliminated
	Compulsory registration	Declarative. Ex officio by autonomous community for low voltage up to 100 kW
Suppress restrictions and barriers	Free transfer of surplus	A compensation mechanism is introduced
	Only in internal grid	Distribution grid is introduced
	Only one prosumer	Various prosumers is introduced

Table 1: Highlights of RD 15/2018

In addition, on 6 April 2019, the published RD 244/2019 regulating administrative conditions, technical and economic aspects of self-consumption, which covered all the necessary processes to fully develop self-consumption in Spain, and developed many points already established by the RD 15/2018. Under the new legislation there are two ways of valuing surpluses: *Autoconsumo con excedentes con compensación simplificada* and *Autoconsumo con excedentes no acogido a compensación simplificada*. The consumers eligible for these two types of compensation are:

Type of compensation	Con excedentes con compensación simplificada	Con excedentes sin compensación simplificada
Condition	Installations with total inverter power less than or equal to 100 kW	When they do not meet the criteria of the previous or voluntarily do not wish to avail themselves of this modality. In this case, they will receive the corresponding economic compensation for the excess hourly electricity produced. It operates like any other energy generation facility, subjected to normal taxation
	That they benefit from the surplus compensation contract	
	Have a joint contract for auxiliary production and supply services	
	That they are not covered by the specific remuneration system	

Table 2: Explanation of different self-consumption compensation modality

3.2.1 *Self-consumption with excess with simplified compensation*

This mechanism is a process that allows consumers to sell their solar energy automatically and easily. The sale price of the surplus is approximately 0.02 - 0.08 €/kWh. It is important to note that the total monthly sale of the surplus can never be higher than the price paid for the energy consumed. The compensation of surpluses for a solar panel installation will be done on a monthly basis. This will allow consumers to save between 30% and 65% of the total price of their electricity bill, depending on the hours of consumption and the amount of daily surplus.

We must remember that this does not equal to net energy metering, in which the energy used is compensated for and not the price paid for it. Therefore, since the price of energy sold is less than half the price of energy purchased, consumers must sell more than twice the energy used from the grid if they want to minimize their electricity bill.

Category	Type of energy	Price
Maximum demand	-	No changes
Energy consumption	Self-consumption	Completely free and excluded from tax
	Grid	Same price and tax
	Excess	Approximate price 0.05 €/kWh. Total compensation cannot exceed the total price of energy consumed from the grid. Subjected to a 7% generation tax
Electricity tax + IVA	-	Will be applied to final payment after the compensated excess

Table 3: Summary of charges in this mechanism

3.2.2 Electricity Billing Mechanism

In the past, the entire electricity market was regulated, and prices were set by the government. The market began to be deregulated in 1997 and within this process, 2009 was a very important year. Since then, consumers have been able to choose the type of market they wish to be in, regulated or free market. At the moment, the billing system used is known as the time-of-use billing. Meaning that customers are charged based on peak and off peak tariff. Currently, there are three time-of-use category:

A) General tariff
B) Time-of-use tariff or hourly discrimination
C) Super-valley tariff or EV tariff

The following is a calculation example, based on the average electricity consumption of 3487 kWh annually. Prices are taken from Tarifa Coche Electrico by Lucera.

a) Maximum demand – This concept is a fixed amount that the consumer must pay based on the power contracted measure in kW. This value depends mainly on the size of the house and the number of electrical appliances that the consumer needs to use simultaneously

Maximum demand = kW contracted × price per kW per day × number of billing days
Example = 5.5 kW × 0.1042 €/kW/day × 30 days = €17.193

b) Energy consumption – This concept is a variable amount that refers to the energy consumed in the billing period. It is measured in kWh that includes the payment for access to the grid.

Energy cost = kWh consumed × price per kWh
Example P1 = 122 kWh × 0.149 €/kWh = €18.185
Example P2 = 96 kWh × 0.085 €/kWh = €8.151
Example P3 = 73 kWh × 0.068 €/kWh = €4.940

c) Electricity tax – All persons with access to electricity from the grid must pay this tax, regardless of whether or not they consume electricity at the point of supply. It is a non-IVA tax, regulated by the government and applied over the term of maximum demand and energy consumption. The percentage of this tax is 5.11269632%.

Electricity tax = 5.11269632% × (a + b)
Example = 5.11269632% × (€17.193 + €31.275) = €2.478

d) Meter rental – This concept appears on the bills of users who do not own the electric meter. The electricity retail company is obliged to collect this meter rental that is owned by the corresponding electricity distributor. The government establishes maximum prices for the rental of meters. The price varies depending on the type of meter installed. Digital meters have a price of €0.026452 per day or €0.80 per 30 days.

Meter rental = €0.026452 × number of days
Example = €0.026452 × 30 days = €0.794

e) IVA – Value added tax by applying 21% to the sum of the 4 previous concepts and adding it to the final price.

IVA = 21% × (a + b + c + d)
Example = 21% × (€17.193 + €31.275 + €2.478 + €0.794) = €10.866

f) Final price – The sum of all the concepts, to be paid to the retail company.

Final price = a + b + c + d + e
Example = €17.193 + €31.275 + €2.478 + €0.794 + €10.866 = €62.61

The current legislation allows self-consumption to nullify only the energy production cost*. This applies to all domestic consumers regardless of the electricity retail company that they are with. Under the most optimistic situation and assuming that the customer reaches 100% energy independence, the consumer will still be charged €22.83.

Charges	Before	After	€ Difference	% Difference
Maximum Demand	€17.193	€17.193	Null	Null
Energy consumption	€31.275	€0	€31.275	-100%
Electricity tax	€2.478	€1.599	€0.879	-64.5%
Meter rental	€0.794	€0.794	Null	Null
IVA	€10.866	€6.904	€3.962	-63.5%
Final price	**€62.61**	**€22.83**	**€39.78**	**-63.5%**

Table 4: Maximum savings achievable by a domestic consumer

This is highlighting the fact that Spain currently has the highest weight of fixed charges (or maximum demand) at 40%, considerably higher than the EU average at 22%. It is an exceptional situation that must be corrected: only through a reduction in the weight of said charges, consumers will see higher savings of self-consumption.

However, 2019 recorded a history when 459 MW of new PV self-consumption were installed, doubling the installed power in 2018, which was 235 MW. Of these 459 MW, UNEF estimates that the majority of the installations, between 50-60% has been installed in the industrial sector, 30-40% in the commercial sector and 10% in the residential sector. This shows that although the legislation is not as favourable as it could have been, more and more consumers are betting on this technology to reduce their electricity expenses and their carbon footprint.

4. Technological Marketing Environment

4.1 Electric Powered Appliances Potential

The penetration rate of electric powered household appliances varies according to the application. The electric powered appliances penetration rate might correspond to the following three factors:

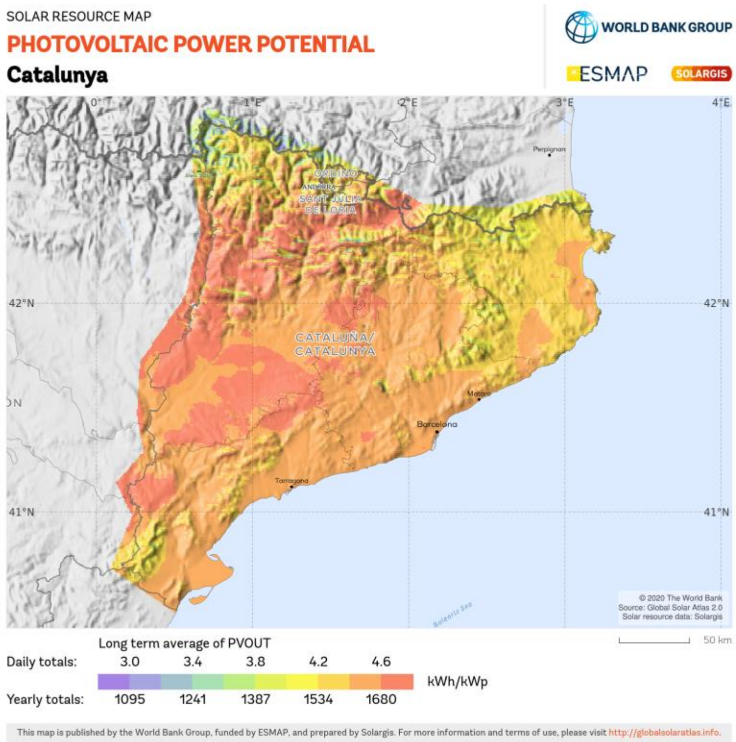
a) Technological availability – Cooling is nearly 100% powered by electricity as it is the most effective energy source that can convert electricity into refrigeration.
b) Price - For cooking, both gas and electric stoves are in essentially the same price range, depending on the brand and model. However, as heating represents almost half of the energy consumed at home, majority of the population chooses non electric powered heating due to its lower operational cost.
c) Performance or efficiency – It is well known that heating, hot water and cooking appliances are more energy efficient when they are powered by a combustible energy source. Apart from that, fossil fuels can produce heat at a much faster rate due to the combustion thermal factor, again contributing to its high energy efficiency.

Purpose	Type/Source	Percentage	Penetration Rate
Heating	Electricity	46.3 %	46.3 %
	Natural Gas	32.0 %	
	Liquefied Petroleum Gas	4.5 %	
	Gas	14.3 %	
	Carbon	0.9 %	
	Renewables	1.9 %	
Cooling	Electricity	99.7 %	99.7 %
	Renewables	0.3 %	
Hot water	Electricity	21.5 %	21.5 %
	Natural Gas	40.3 %	
	Liquefied Petroleum Gas	25.9 %	
	Carbon	0.1 %	
	Renewables	1.7 %	
Cooking	Electricity	63.0 %	63.0 %
	Natural Gas	17.9 %	
	Liquefied Petroleum Gas	18.9 %	
	Carbon	0 %	
	Renewables	0.2 %	

Table 5: Energy source of household appliances in the country, 2017

4.2 Solar PV Potential in Catalonia

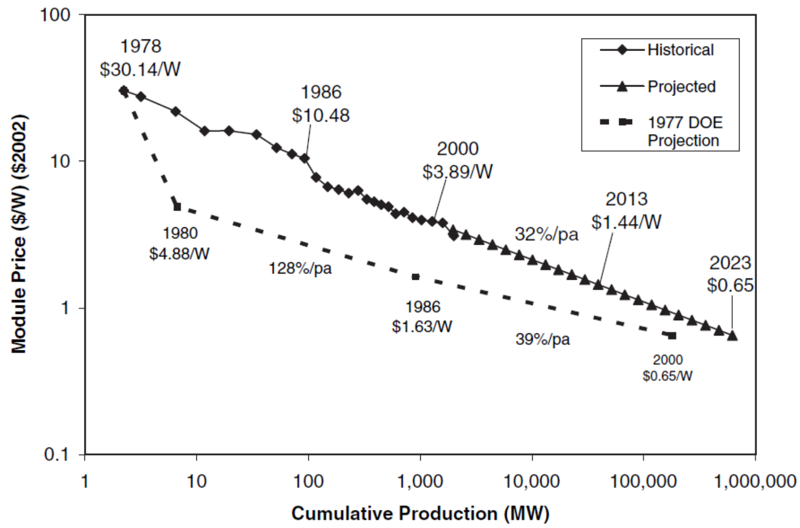
A solar PV system converts the sun's radiation, in the form of light, into usable electricity, due to photovoltaic effect. When the sun light hits the semiconductor within the solar cell, electrons are freed and form an electric current. As PV systems convert light directly into electricity, they are not to be confused with other solar technologies, such as concentrated solar power or solar thermal, used for heating and hot water.



Picture 9: PV power potential of Catalonia, 2020

An early 2019 market research conducted by Solarwatt showed that the rapid technological evolution of solar PV is seen as a discouragement for some, and as an encouragement for others. Consumers tend to think that the longer they wait, the better the technology becomes. The logical thinking that goes behind this is the better the technology gets, the higher the potential savings. Some consumers also think that it is better to wait for the technology to become cheaper and better in order for it to be profitable. In other words, consumers' perspective on solar PV technology as of today is that it is not mature enough as a profitable investment.

According to Swanson's law, the price of PV panels tends to drop 20% for every doubling of cumulative shipped volume. At present rates, costs go down 75% about every 10 years. The research paper contributing to this law was first published in 2006 and since then, the industry's learning curve kicked in even more dramatically. What this law shows is that we are well on our way to seeing solar panels cost almost nothing -- and there is no hyperbole in this statement. A key message in the law is this: getting to scale is the most important factor in bringing costs down. There are many other factors, however, that is important for bringing costs down, including streamlining permitting, lowering installation costs and reducing the costs of end customer acquisition.



Picture 10: Extension of the PV panel pricing historical curve, 1978 – 2023

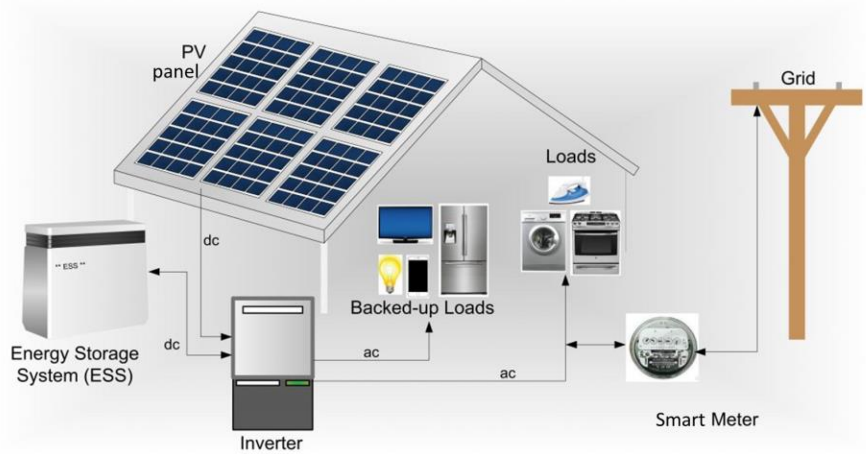
What Swanson's law did not address, however, is the balance of system of PV systems today, which is represented by labour and other equipment such as inverters, racking and wiring. The panel costs now account for a far less significant fraction of the total cost of a system than they did just a few years ago, making labour costs and balance of system costs more prominent. Moreover, panel prices across the globe are fairly similar because of the global commodity market for solar panels.

4.2.1 PV System Components

The first component of a PV system is the PV panel itself. A PV panel is made from a set of PV cells made from various semi-conductor materials. The most commonly used material today is silicon. A PV panel has an average lifespan between 20 to 30 years. Most PV panels usually have efficiencies between 16 to 19%, and some even up to 23% depending on the technology.

An inverter is a critical component of any PV system as it converts the DC electricity generated by the PV panels into usable AC electricity. It usually has an average lifespan between 10 to 15 years, while some up to 25 years. They are highly efficient, with up to 98% efficiency in some cases.

A Smart Meter is a bidirectional energy meter which optimises self-consumption and records a household´s load curve. It also transmits information regarding the connection to the grid and the inverter. The device is connected to a built-in data logger that allows the consumer to visualise daily energy balances with load curves and instantaneous power balances within the PV system. Among other things, the consumer can directly monitor savings in real time and the avoided CO_2 emissions. All of these features allow consumers to monitor their consumption times and change their consumption pattern if needed, ultimately to achieve bigger savings. This device is the key to a successful integration with smart home appliances.



Picture 11: Schematic of a domestic PV system with a battery

4.2.2 Architectural Integration

In the process of retrofitting PV systems into an existing or a newly built house, PV panels are most commonly considered just as technical devices. However, considering PV panels as building components that are integral parts both of the constructive system and the overall architectural design leads usually to good architectural solutions. The IEA has given an overview of the criteria for good PV system architecture:

a) Natural integration of the PV system
b) The PV system is architecturally pleasing, within the context of the building
c) Good composition of colours and materials
d) The PV system is in harmony with the building and as a whole forms a good composition
e) The PV system matches the context of the building
f) The PV system and its integration are well engineered
g) The application of PV system has led to an innovative design

Complying with how buildings are built today, roof mounted PV systems are usually mounted flush on the roof, ranging from a 0° flat roof to 35° inclination. Furthermore, roof orientation at less than 90° or more than 270° are less likely to have a favourable solar energy yield. In particular for buildings which are situated in an urban context, it is often difficult to avoid shading problem, because of the presence of trees, chimneys or other buildings. Contrary to popular belief, a house could have a south-facing roof at the optimal tilt angle, but if the PV panels are shaded, the energy production may suffer greatly. Protruding objects on the roof that may cause shading on the PV panels such as chimneys should be built in the least obtrusive location. That said, an inclination between 15° to 40° and orientation between 90° to 270° is acceptable for PV system installation.

4.3 Lithium Ion Battery Potential

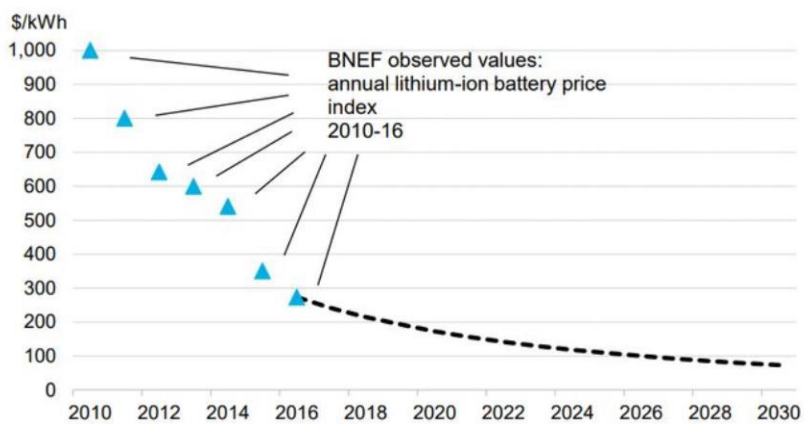
A lithium ion battery is a rechargeable ESS that stores energy from a PV system and provide that energy to the consumer for a later use, thus reducing the amount of grid electricity the consumer needs to buy. The general range for a lithium ion battery's useful lifespan is between 10 to 20 years. The charging-discharging efficiency of today’s technology frequently exceeds 95%. It is also important to note that, contrary to expectations, some batteries are not designed to work during power-cuts. But they are not for everyone, as households generally need to be generating surplus solar electricity to store. At today’s prices, poorly designed systems may not repay the initial investment. But prices continue to fall, and the technology is also improving, meaning that battery is becoming a viable economic option for some households.

Annual Electricity Consumption (kWh)	Battery Size (kWh)	Self-Consumption	Self-sufficiency	Cost
3487	9.0	48 %	72 %	€6500
	7.7	47 %	71 %	€5800
	6.4	45 %	68 %	€5000
	5.1	42 %	63 %	€4000

Table 6: Different battery sizes when paired with a 5 kW PV system

Bloomberg New Energy Finance estimates that energy storage will grow exponentially in the coming years thanks to the reduction in battery costs that will continue its trend (-85% from 2010 to 2018). Driven by electromobility and utility-scale applications, we can expect to see an additional decrease of 50% until 2040. For this international scale analysis, the storage-renewable binomial, especially with PV, has become an engine for technology, considering that utility-scale batteries will constitute the majority of the storage deployment by 2040.

For many, numbers like these that declare lower and lower prices can stir them to action. For others though, these same numbers can cause them to wait a few more years in hopes of saving even more money.



Picture 12: Market estimation of lithium ion based ESS, 2010 - 2030

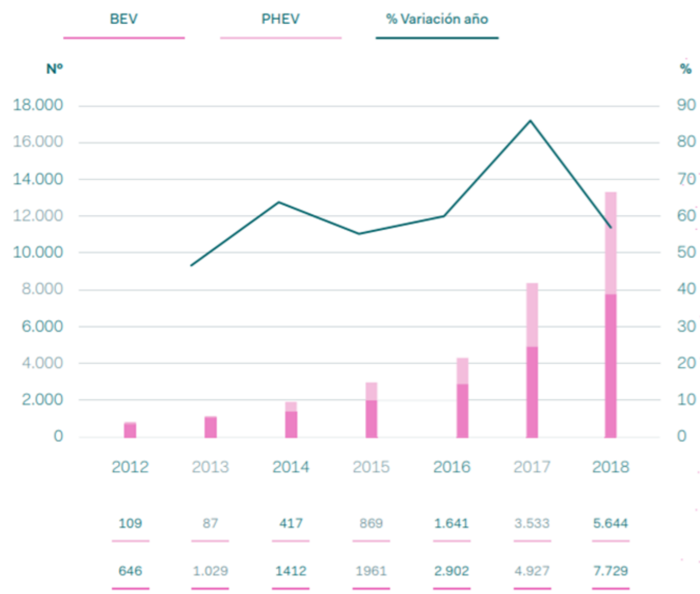
4.4 Electromobility Potential

The same can be said with the electromobility market potential. Choosing between a petrol, hybrid or electric car is a dilemma not seen since the late 1880s, when people sat around trying to decide between a Benz Patent-Motorwagen and a new horse. The obvious solution would seem to be to buy an electric car, but the even more obvious solution is to buy an electric car in five years' time. A likely scenario playing in their mind is that in a few years they might get a longer distance, faster charging and cheaper car.

Electromobility becomes an essential element of the energy transition insofar as it allows the incorporation of renewable energy, into the transportation sector, which as of 2018 represents

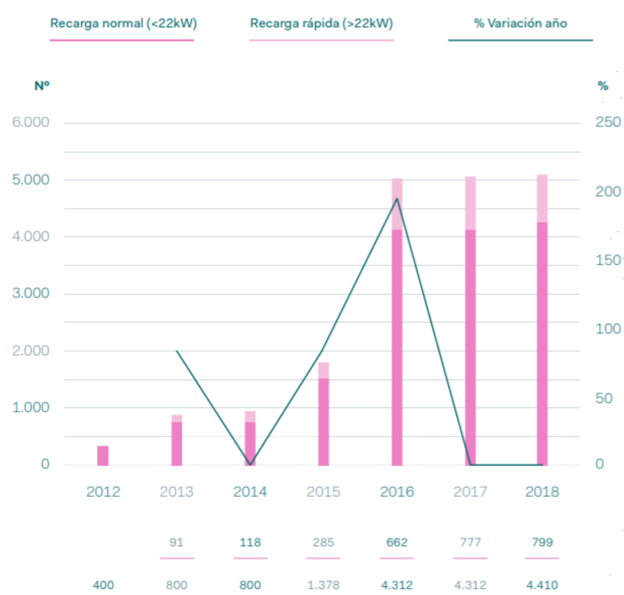
40% of final energy consumption, and which only 6% is of renewable origin. By 2030, The Integrated National Energy & Climate Plan aims to have 5 million EVs circulating the road.

In 2018, around 40,000 EVs (both BEV and PHEV) circulate nationwide. From this figure, Basque Country leads the market share with 21.9%, followed by Catalonia at 20.5%. This highlights the fact that Catalans are adopting this technology faster than their counterpart from other regions. The increasing adoption is appreciated year after year, highlighting an increment of close to 90% in 2017 over the previous year.



Picture 13: Yearly New Registrations of EVs in Spain, 2012 - 2018

EV charging infrastructure is one of the biggest anxieties that deters people from venturing into electromobility. From 2014 until 2016, there was a massive 200% increase in evolution of public EV charging points when compared to the previous year. On the contrary, the following two years has seen a stagnation in its deployment.



Picture 14: Evolution of public EV chargers, 2012 - 2018

EV charging at home is often the most convenient and cost-effective way to recharge an EV. Most home chargers are either rated at 3 kW or 7 kW. The caveat with EV chargers is, like our smartphone chargers, the lack of universal compatibility. Different electric cars have different charging ports and different maximum charging speed. The limiting factor in rated power of EV chargers is usually the grid connection - a standard domestic single phase 230 V supply will not be able to achieve a charging rate of more than 7.4 kW. Even with a standard commercial three phase connection, the power rating for AC charging is limited to 43 kW. Greater charging power (≥ 50 kW) can be achieved with rapid DC chargers. The table below shows some of the commonly found domestic EV chargers.

Supply Type	Rated Power	Charging duration for daily commute, 40 km	Charging duration from 0 to 80%, 40 kWh battery	Estimated Cost
Three phase, 63 A	43 kW	7 min	45 min	€12000
Three phase, 63 A	22 kW	16 min	1 h 30 min	€2500
Three phase, 63 A	11 kW	28 min	3 h	€1800
Single phase, 32 A	7.4 kW	48 min	5 h	€1300
Single phase, 16 A	3.7 kW	1 h 45 min	9 h 40 min	€500
Power outlet, 13 A	3.0 kW	2 h 30 min	11 h	€0

Table 7: Typical residential EV chargers

Many EV chargers nowadays offer intelligent charging solution. For example, certain chargers can be programmed to charge the car during off-peak hours although the car remains plugged outside the off-peak hours. Although it is possible to charge an electric car from the typical power outlet, it is unrecommended to do so as unlike these outlets, the charger allows you to adjust the power to prevent the household electrical load from overloading.

5. Design Process: Evidence Based

5.1 Energy Consumption Scenario

To begin, the energy consumption scenario of the sample household is an average household as defined in a report released by IDAE and Eurostat "Consumos del Sector Residencial en España, 2017". The household consumes 10520 kWh per year, of which nearly half is dedicated solely for heating. It is also understood that the average electricity consumption is 3487 kWh per year. This means the 7033 kWh remaining energy, or around 67% comes from non-renewable energy sources. We can safely assume that this percentage is represented by heating and hot water. As seen before in 4.1, these two represent the lowest share of electric powered appliances penetration rate, standing in at 46.3% and 21.5% respectively.

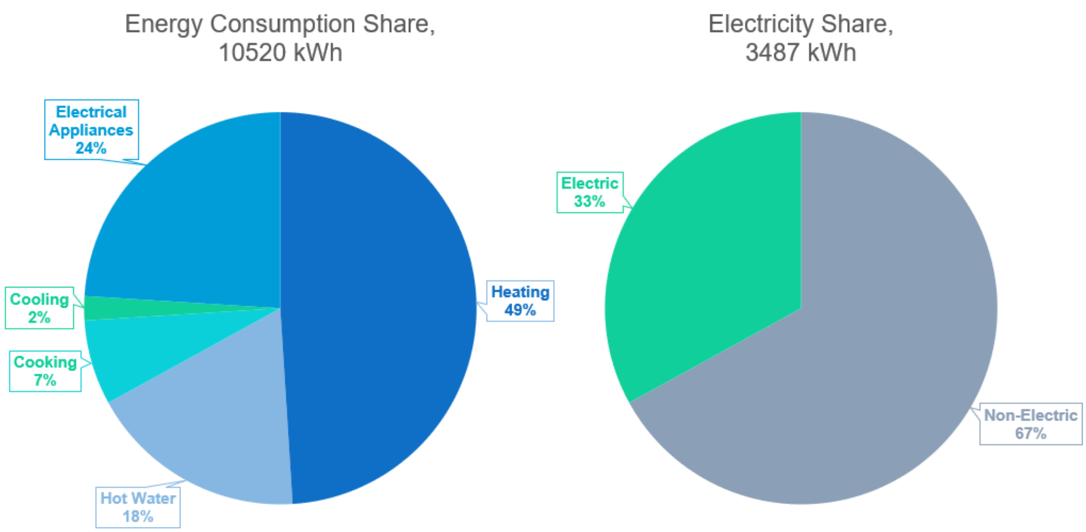


Figure 1: Sample Household Energy Share – 33% electric

In order to meet the zero carbon vision, the household energy ecosystem will have to be fully powered by electricity. Moreover, the household electricity consumption will increase by 2095 kWh to recharge an electric car at home. This is assuming that the car travels 14600 km a year, or 40 km per day. Plus, this is also assuming that the car will be "refuelled" only when parked at home – which is possible with electromobility. Theoretically, the overall electricity consumption would increase to a whopping 12615 kWh, up by 361% from the previous 3487 kWh. When calculated under the same method as 3.2.2, the final monthly electricity bill would be €166.73, up by 266% from the previous €62.61.

The above scenario is most likely one that everyone wants to avoid. This is the biggest barrier to going 100% electric. Consumers are already aware that they are paying too much for their electricity. Due to this factor, it is difficult to justify the move to own an all-electric household, let alone pairing it with an electric car. The obvious choice for many, is a more affordable option.

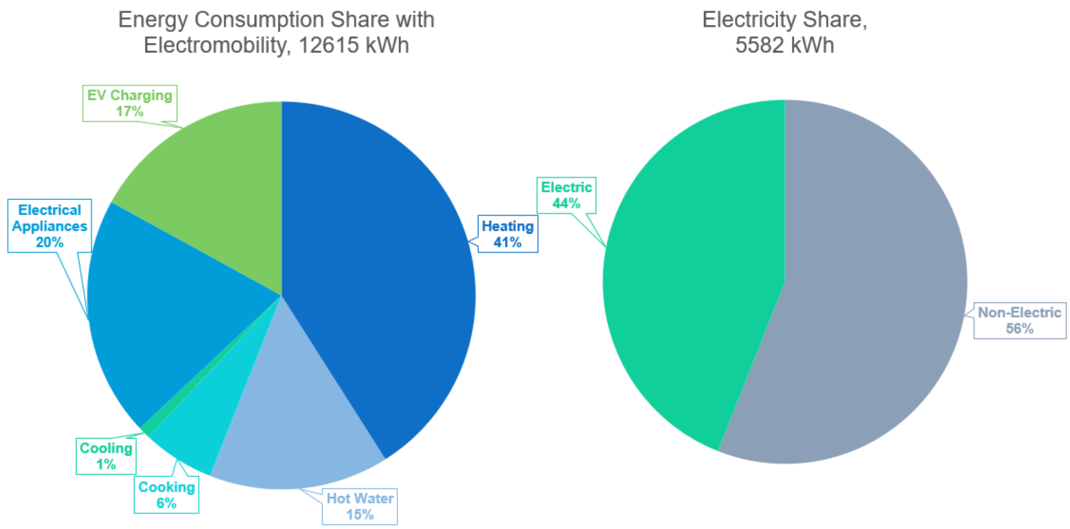


Figure 2: Energy Share with EV Charging – 44% electric

5.2 Design to Reduce Energy

The first step of designing a full electric house is to identify the most ideal and cost-effective method to reduce the final electricity consumption. After all, energy efficiency plays a major role in low carbon energy transformation. As seen in the previous figure, heating and hot water quantify 56% of the energy consumption. Besides that, electric based heating and hot water is not a famous choice for consumers in the country.

This leads to reversible heat pump. A heat pump is a device that transfers thermal energy in the opposite direction of spontaneous heat transfer, by absorbing heat from a cold space and releasing it to a warmer one. Moreover, it is significantly more energy efficient than simple electrical resistance heaters. A typical unit can produce around 3 to 4 kWh thermal energy for every 1 kWh of electrical energy consumed. This efficiency however begins to decrease as the outside temperature decreases, making them more efficient in hotter climates than cooler ones – suitable for its application in Catalonia. Recently, the peak of electricity demand in many areas of Catalonia has shifted from winter to summer due to air conditioning.

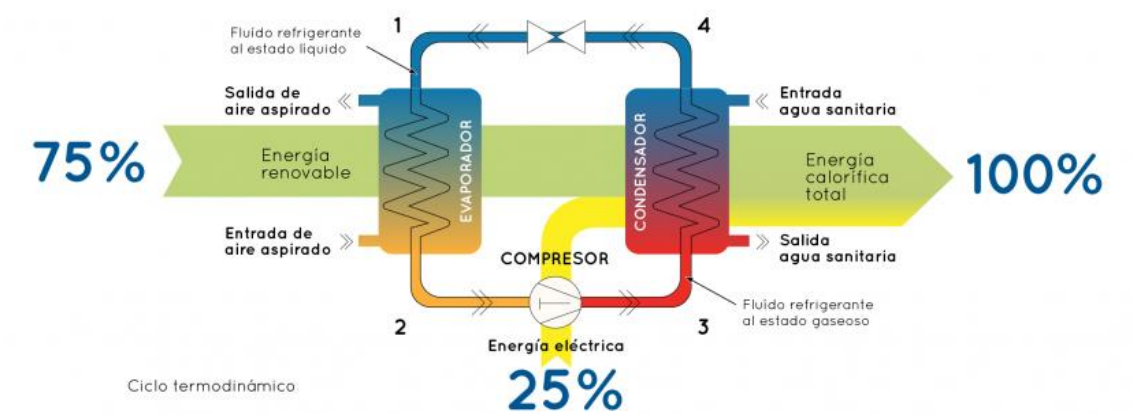


Figure 3: Reversible heat pump flow diagram for heating, cooling and hot water

The versatility of reversible heat pumps is not only because it is suitable for heating and cooling, but also for domestic hot water. On the flip side, this technology is a little bit slow in warming up water – which is why it is recommended to have a hot water storage tank. For this sample household, a 4 kW heat pump with 100 litres storage tank is used, granted that the average hot water consumption at 60℃ is at 28 litres per day.

5.3 Design to Produce Energy

Solar PV is arguably the best technology available to generate and self-consume electrical energy today. By harvesting the endless power of the sun, it is pollution free and requires minimal maintenance throughout its life cycle. In addition, domestic PV system will contribute to the increase of renewable energy share of the country – although by a small percentage.

Electrical energy produced by a PV system depends on several external factors. Foremost of these is the amount of solar radiation falling on the surface of the panels, which in turn depends on the local climatic conditions as well as the tilt angle and the orientation of the panels.

Meteorological data shows that the amount of sunshine in Catalonia is very good in summer on the coast and in inland south-central areas. This is considering 3 hours of peak sun during winter and 7 hours of peak sun during summer in Catalonia. Spring and autumn are typically the rainiest seasons, which helps to self-clean the panels. The inland part of Catalonia – which is hotter and drier in the summer – has the best solar power potential in the region. As a general guideline, the best tilt angle for maximising energy yield is at 36°, facing 180° or true south.

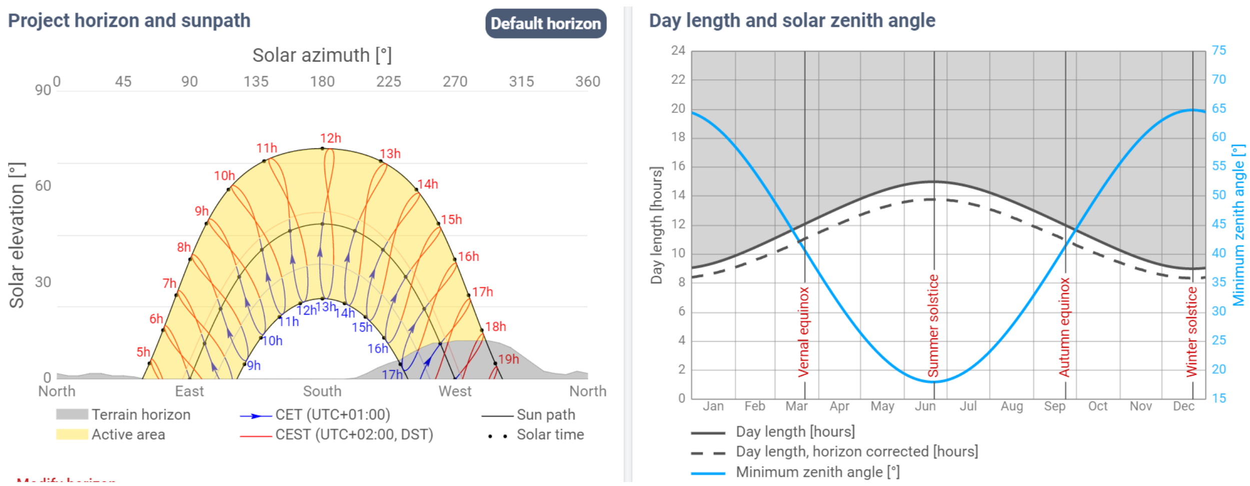


Figure 4: Sun path for solar energy yield in 08041 Barcelona

For this sample household, a 5.28 kW PV system comprising of 16 panels are fitted on the roof facing true south at 20° tilt angle. The panels are connected in series to form two strings into a 5 kW single phase inverter. It is the optimum size based on today's market with a good combination of cost vs performance ratio.

Lastly, the house is paired with a 3.68 kW EV charger. It is a rather slow charger for a modern electric car nowadays, taking approximately 9 hours and 40 minutes to charge from 0% to 80% capacity as seen in 4.4. The choice is justified by the structure of the current billing mechanism – higher power means a significantly higher electricity bill regardless of the consumption. It is hence believed to be sufficient for the average user. The following is an exterior visualization of the sample household.

Figure 5: Exterior visualization of the energy ecosystem

The result is astonishing. The electrical energy demand is reduced to 8214 kWh, close to 35% decrease from 12615 kWh. Heating, cooling and hot water combined now represents 32% of the overall electricity consumption – second to electrical appliances at 34%.

The figures obtained above are taken from a simulation done in Sunny Design Pro – a software that offers comprehensive planning and simulation of energy systems. The simulation was done for a house in 08041, Barcelona. The meteorological settings were left at default, leaving the average ambient high temperature at 24℃, with annual extreme low at -1℃ and annual extreme high at 33℃. With this, we can now assume that this shall be the new average electricity consumption of an all-electric household with an electric car.

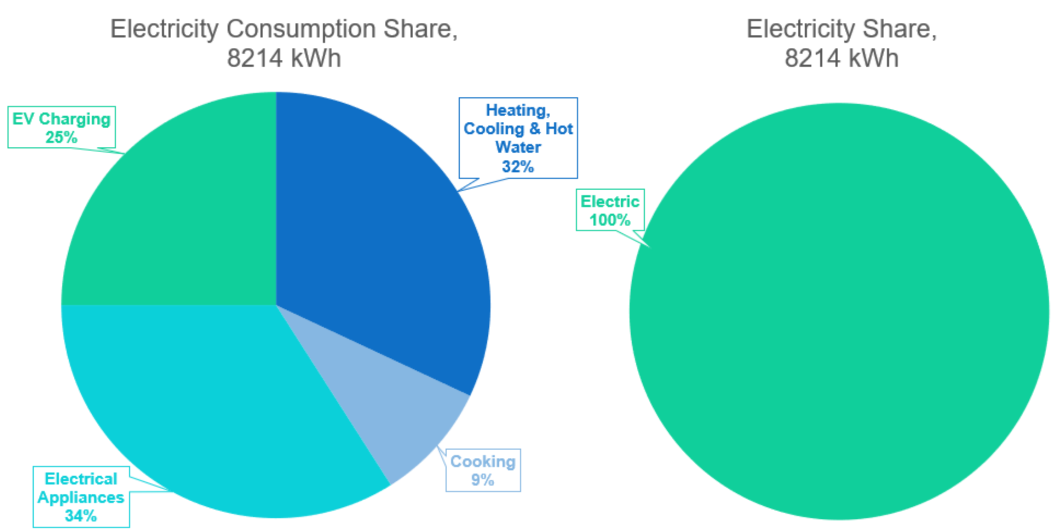


Figure 6: Energy share after conversion to 100% electric

5.4 Energy Ecosystem Simulation Result

The simulation result is less convincing than expected. The self consumption amounted to only 23.8% of the solar energy generated. This means that most of the energy generated is actually injected into the grid instead of being consumed. As previously mentioned, consumers are feeling under rewarded due to a compensation rate at roughly 1/3 of the purchasing price. This is where citizens will start questioning the viability of having a PV system.

Furthermore, the idea of living in an ecosystem where your electric car is charged by the power of the sun is nowhere near reality. The PV system actually contributes 0% to the electric car's energy requirement. This is rather simple to be explained, as the electric car is driven to work during the day and left to be charged at night.

Nonetheless, it is not all that bad as the renewable energies share of the house has reached 100% and CO_2 emissions are all but gone. The PV system will also eventually pay off itself in approximately 11.6 years, saving around €12500 of electricity bill over the period of 25 years. For some, it may still be an attractive investment as the internal rate of return of the PV system hovers above 8% - the minimum benchmark for many investors.

The following is a summary of key figures of the PV system. All economic figures shown below are before tax.

Key figures

Energetic (annual values)		Economics	
Total electrical energy consumption:	8,214.20 kWh	Investment costs:	7,500.00 EUR
Electrical energy generated:	7,806.80 kWh	Total savings:	12,538.07 EUR
Self-consumption:	1,856.35 kWh	Amortization time:	11.6 a
Self-consumption quota:	23.8 %	Annual return (IRR):	8.2 %
Self-sufficiency quota:	22.6 %	Relative energy cost savings:	50.8 %
Solar fraction:	0 %	Electricity purchase costs:	19,395.91 EUR
Percentage of purchased energy savings:	50.5 %	Energy purchase costs:	19,395.91 EUR

Total savings after 25 year(s)

12,538.07 EUR

Energy purchase costs

Year	before	after	Savings
1	1,050.09 EUR	**531.99 EUR**	**49 %**
25	2,198.65 EUR	**1,081.42 EUR**	**51 %**

Figure 7: Energetic and economic summary of the standalone PV system

5.5 Energy Consumption Pattern

Where the consumption patterns align well with sun hours, high rates of PV self-consumption and energy independence can be achieved jointly. It is easier to achieve this balance in commercial facilities, such as supermarkets, offices and factories, than in households. In offices and supermarkets, PV self-consumption rate can reach 90%, since the power generated during the day is used at peak times. In this situation, self-consumption can make an important contribution to finance the energy transition.

The sample household in this paper has an energy consumption pattern of an existing single-family home consisting of 2 adults and 2 children. Both parents are in full-time employment from 8:00am to 5:00pm and the children are of school age.

Figure 8: Typical energy consumption pattern

Ensuring that the energy generation and consumption occur simultaneously is a challenge. A household typically consumes between 20% to 40% of its self-generated solar power, provided that it does not own a battery. Explaining the weakness of the self-consumption rate is simple: more power is generated at midday, when the sun is at its highest but houses are often empty, while peak consumption often takes place during the morning, and in the evening from 8:00pm, when families are their most active at home. In other words, there is a mismatch in supply and demand. This is not an engineering problem. It is a data management problem – natural for intelligent systems.

5.6 Electromobility Consumption Pattern

Typically, EV owners would be pressed to charge their car at night between 01:00h – 07:00h, especially since EV tariffs out there offer the cheapest electricity at these times. This is because energy firms are looking at passing on reduced off-peak energy prices to encourage drivers to charge when the grid is least congested. Through this, the grid will require less investment in the future – costs that would otherwise inevitably be passed on to the customers. However, households with higher electricity consumption during the day may end up worse off overall since peak tariff typically increase a little on such tariffs.

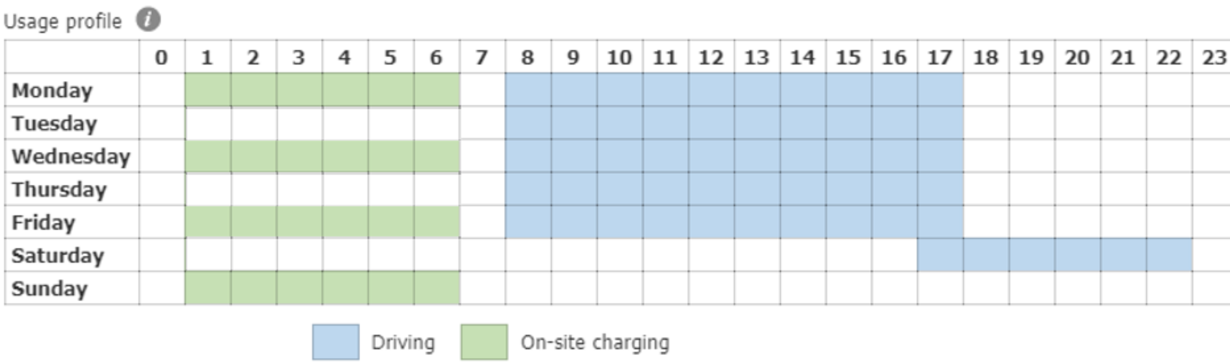


Figure 9: EV charging vs driving pattern

Coupled with high electricity prices, it seems like PV self-consumption is a questionable investment for domestic consumers who are looking to reduce their energy expenses – at least for those who consume their electricity like aforementioned.

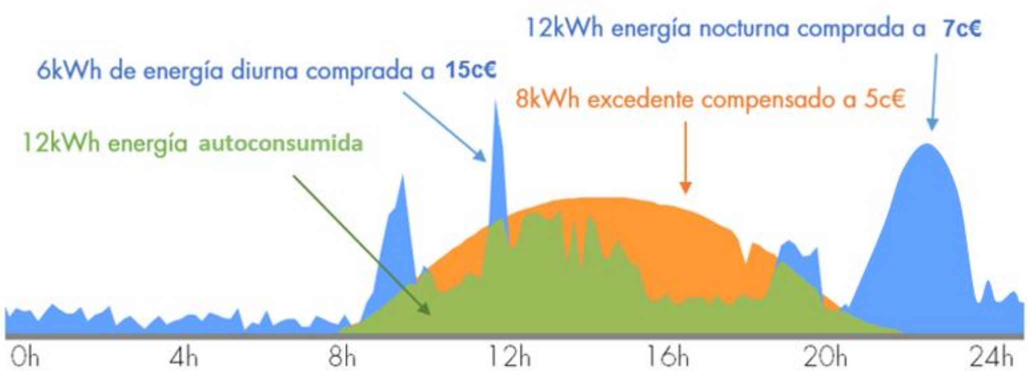


Figure 10: Energy generation vs consumption pattern

5.7 Energy Ecosystem with Lithium Ion Battery Simulation Result

A well-known solution to tackle such problem is by adding a lithium ion battery to the household. The battery system would store excess energy from the PV system and provide that energy to the consumer for a later use, such as charging the electric car at night – thus reducing the dependency level to the electricity retail company.

In some cases, consumers who opt for this solution wants to have a better control of their energy system. Ultimately, in order to disconnect from the electric grid, the consumer should oversize the size of the panels and the battery consisting of a few days' worth of backup power to account for days where there would be little sun – e.g. in winter.

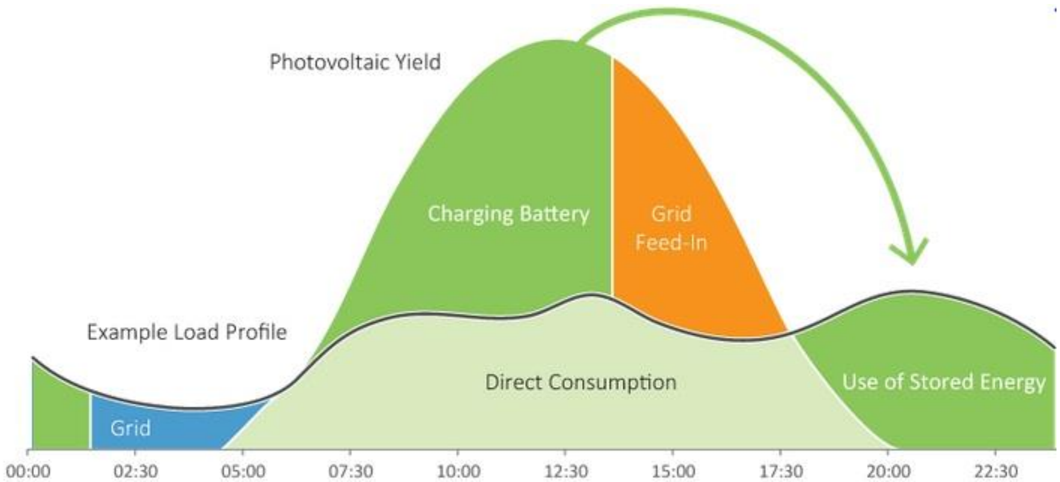


Figure 11: Use of battery to increase self-consumption

A simulation is carried out with the same parameters used previously, with an additional 6.4 kWh lithium ion battery programmed to maximise the self-consumption rate.

As expected, the self consumption has more than doubled to 51.3% of the solar energy generated. On the other hand, the energy system still contributes 0% to the electric car's energy requirement. A typical consumer would certainly find this surprising as the battery is not being used as it was intended to be. A further look into the simulation report suggests that all the energy stored in the battery is fully used up before midnight. This tells us that a bigger sized battery should be used instead, roughly with a size of 10 kWh.

The problem that arises here is the additional cost involved. The system with 6.4 kWh battery takes approximately 14.5 years to payback itself. It also has a lower annual return at 5.7% and saving only around €13100. Hence, a simulation with a larger battery is not the suitable route to go with as a typical household would be deterred with the hefty investment.

In fact, the total electrical energy consumption has increased to 8406 kWh. The battery system has added 191 kWh to the household's consumption. Moreover, it also did not manage to reduce the maximum demand needed compared to the previous simulation, standing at 6.46 kW.

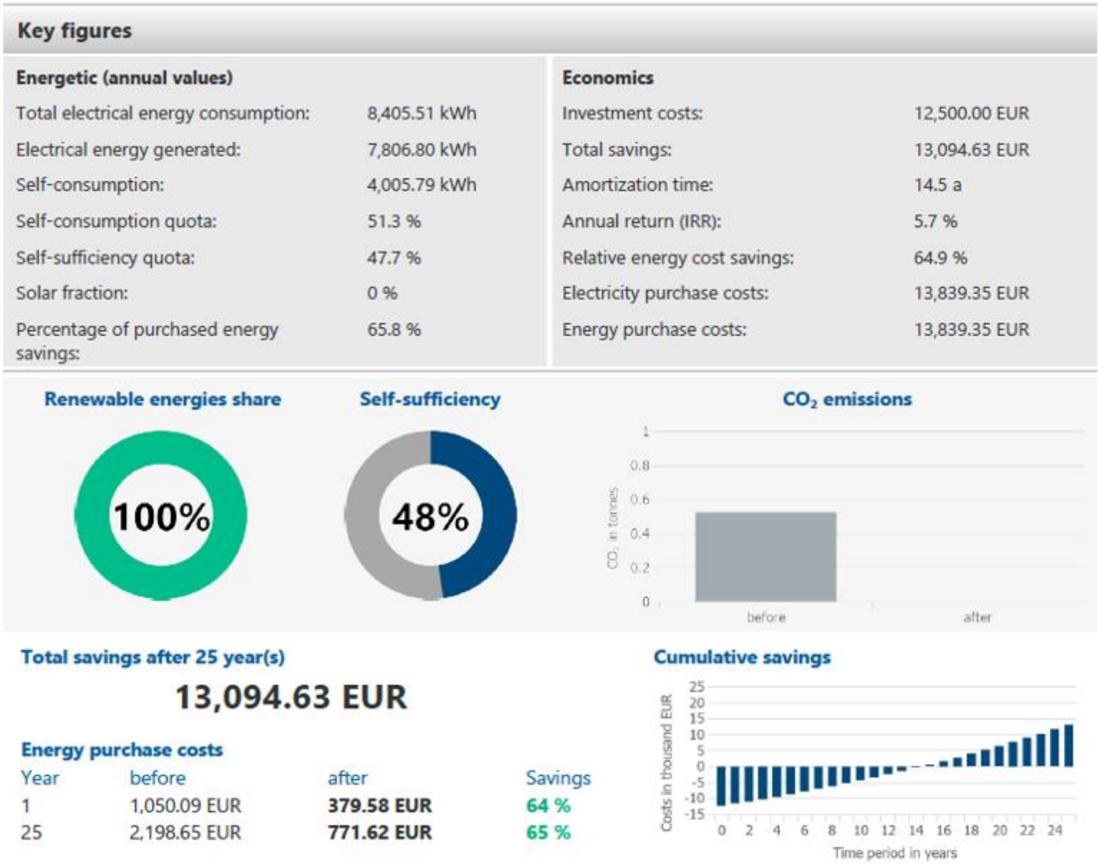


Figure 12: Energetic and economic summary of the PV system with battery

6. Design Process: Data Driven

6.1 Design to Manage Energy Consumption

Smart Energy Management is a system designed to act as the control centre of the household's energy ecosystem, offering intelligent planning and control of energy flows. The aim of this system is to maximise the overlap of solar energy generation and energy consumption – thus increasing the self-consumption rate and maximising savings.

Based on the principle of collective creativity that states "All people who touch and are touched by the product that is being designed should play a role in collective creativity", this system intends to involve an active participation of the consumer in their energy consumption. As we know, energy has pretty much been a foreign topic to a typical consumer. This active participation may potentially allow for a more responsible energy consumption pattern that in turn may help to achieve the zero carbon lifestyle.

The system is not to be confused with smart house or smart home system which requires each appliance to be in constant connection to the internet. This system is rather the missing piece that may complement the smart home technology. This is done by installing an additional software that acts as a communication point between the user, inverter and the smart meter that comes with the PV system. After all, a smart meter is smart due to its capability to communicate with a database – vital to pull data from the local weather station. That being said, the development of this Smart Energy Management do not reject a potential integration with said system in the future as it may unlock a deeper potential.

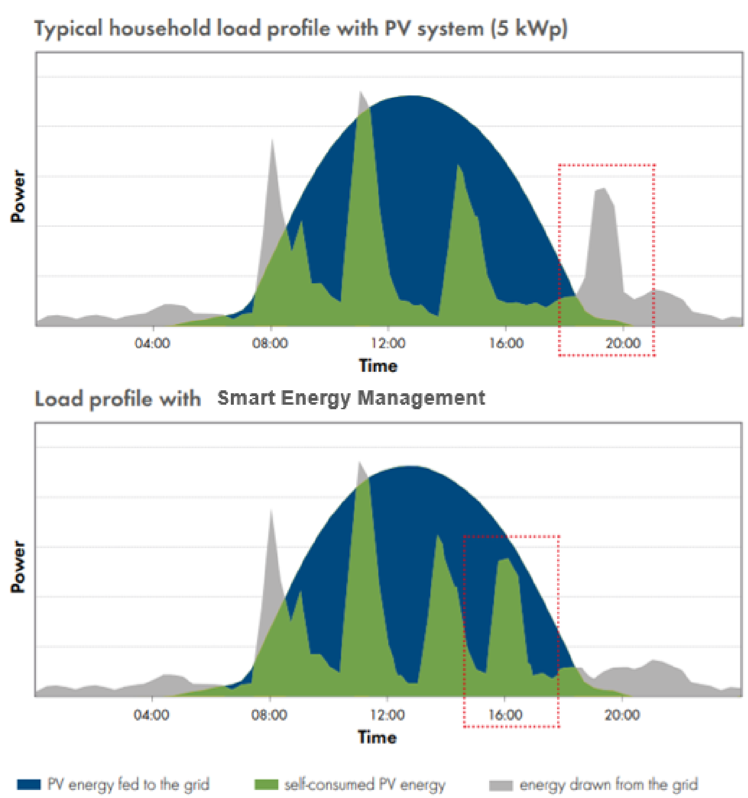


Figure 13: Maximise overlap of generation and consumption

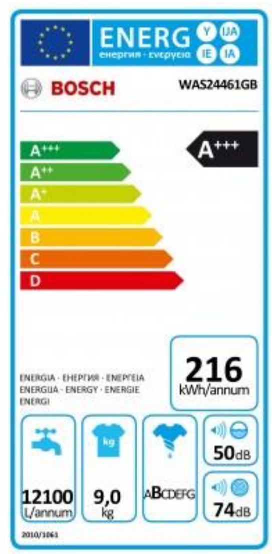
In order to achieve this, we need to leverage the data available around us. By comparing data about the household load, the PV system and the local weather, the system will use a technique known as the regression recommender technique – which is by recommending the user the adequate time to use their loads. This data analysis technique is useful to analyse the above mentioned raw data in order to make user friendly conclusions about their energy usage. Such technique is seen mostly in major eCommerce websites such as Amazon where users are given a list of recommendation of products to buy when they look up for something.

6.1.1 Household Info

a) The first data group is regarding the household information. House loads will be categorised into two sets of data: deferrable load and non-deferrable load. This is done so that the system knows which load can have its use displaced to a more suitable time of the day. The example shown below is used for simulation purpose. That said, the end user can customize the appliance load group as deemed necessary.
   - *Deferrable load:* Use of appliances that can be displaced along the day. Examples are washing machine, dishwasher, shower, EV charging and chargeable devices
   - *Non-deferrable load:* Use of appliances that cannot be displaced. Examples are refrigerator, microwave, stove, heater, air conditioner, lights, television, computers

b) As any other intelligent systems, the more data the system gets the more reliable its output will be. The following step in our data collection is by assigning frequency of use onto said house loads. This will allow the system to distribute the loads more efficiently throughout the week. The frequency shall be customizable by the end user. The following is an example.
   - *Washing machine:* Once every three days
   - *Dishwasher:* Once a day
   - *EV Charging:* Once a week
   - *Electric Scooter:* Once a week

c) Next, the data collection of power and energy consumption of each load. This is crucial for EV charging, as each charging session will drastically increase power consumption. For household appliances, the user can input this data based on the EU energy label. This is potentially the most user friendly method for this data input section as finding the power or energy rating of an appliance can be a headache for many.



d) Additionally, the system can also consider time of-use electricity rates. This is so that a reliable economic saving figure can be calculated to motivate the user. Up to 3 periods can be customised, following the structure of the current billing mechanism. The example used below is Tarifa Coche Electrico by Lucera.
   - *P1 (Peak):* 13:00h – 23:00h at 0.149€ / kWh
   - *P2 (Off-peak):* 23:00h – 01:00h & 07:00h – 12:00h at 0.085€ / kWh
   - *P3 (EV):* 01:00h – 07:00h at 0.068€ / kWh
   - *Maximum Demand:* 0.1042€ / kW
   - *Compensation:* 0.05€ / kWh

e) Finally, location is added into the data collection. Taking into account data privacy and security, a postcode and city name shall be sufficient. This is so that the system can pull data such as solar radiation and temperature from the local weather station. Solar radiation is important for estimating the sun hours. Temperature is for the performance of the panels along with the heating and cooling operation of the heat pump. The following is an example
   - *Postcode:* 08041
   - *City:* Barcelona

6.1.2 PV System Info

The second data group is regarding the PV system so that the system may calculate the daily solar power generation. Basic information such as type of panel, capacity, tilt and azimuth are required. The following is an example

- *Type:* Polycrystalline
- *Capacity:* 5 kW
- *Azimuth:* 180° (true south)
- *Tilt:* 20°

6.1.3 Calculation

Subsequently, a calculation will be carried out to determine the best usage time. The recommended usage time will depend greatly on the orientation of the panels. This is referring to how buildings are built today as most roofs do not face true south – which is the best orientation for maximum solar energy yield. That being said, they will still generate a considerable amount of energy, albeit with a differrent pattern.

Houses with east facing roof will generate a higher portion of solar energy in the morning, peaking at midday. If we consider 600 W/m² and above as peak sun hours in July, the system will recommend to the user to concentrate most of the energy intensive loads between 09:00h and 15:00h. The following figures illustrates this statement.

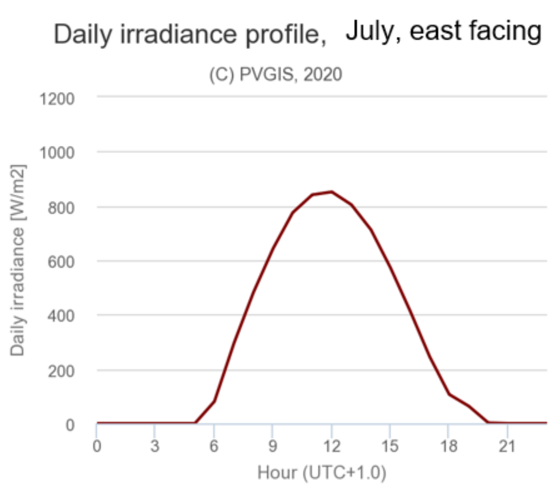


Figure 14: Solar irradiance profile of east facing (90°) roof, 08041 Barcelona

On the other hand, houses with west facing roof will generate a higher portion in the afternoon, peaking at 14:00h. Similarly, the system will recommend to the user to concentrate most of the energy intensive loads between 11:00h and 17:00h.

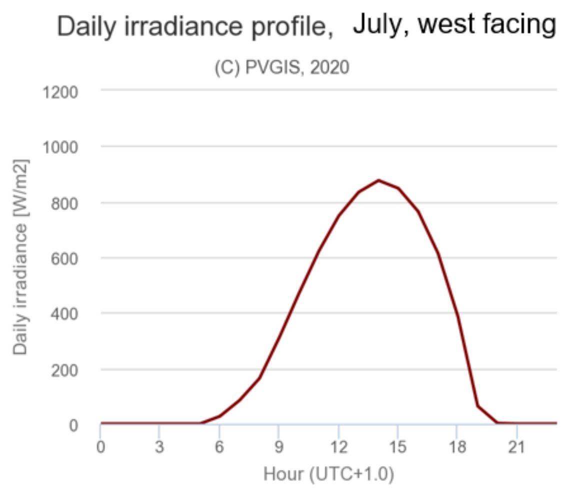


Figure 15: Solar irradiance profile of west facing (270°) roof, 08041 Barcelona

The daily irradiance seen above is the theoretical value from a satellite based weather station. The actual irradiance yield may be lower due to other factors such as shading, potentially caused by a tree or a nearby building. In such case, the Smart Energy Management will compare the local weather data with the actual yield by the PV system. This will give an even more accurate representation of the user's solar power generation.

Next, temperature. In Barcelona, the average ambient high temperature is 24℃, with annual extreme low at -1℃ and annual extreme high at 33℃. As seen before, the efficiency of heat pumps decreases with temperature. During winter, the high afternoon temperature can be exploited to heat up hot water and be stored for later use. This shall be done automatically by a communication link between the heat pump and the inverter.

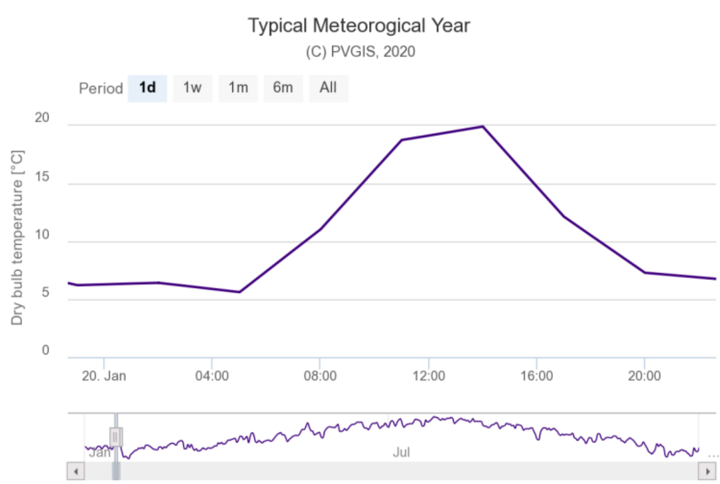


Figure 16: Air temperature of 08041 Barcelona

In the data gathering process, the system will register the frequency of use of each load. The respective loads will then be distributed along the week.

	Washing Machine	Dishwasher	EV Charging	Robot Vacuum	Electric Scooter
Monday	✓	✓			
Tuesday		✓			
Wednesday		✓			
Thursday	✓	✓			
Friday		✓			✓
Saturday		✓	✓		
Sunday	✓	✓		✓	

Figure 17: Data gathering

They will then be pegged with the local weather prediction data for suitability. Assuming that Sunday would be cloudy/rainy, the system will readjust its recommendation to a more suitable time.

Taking into account the parameters mentioned just now, the household would be told to charge their electric car only during the weekend, more specifically between 10am and 4pm. A calculation was made beforehand to uncover if there will be enough charge left in the battery after a busy week of daily driving.

EV model = Nissan Leaf with 40 kWh battery
EV real range = 220 km
Average EV consumption = 144 Wh/km
Distance covered daily = 40 km

$$\text{Energy consumption per day} = \frac{14.4\ kWh}{100\ km} \times 40\ km = 5.76\ \text{kWh}$$

Energy requirement from Monday to Friday = 5.76 × 5 = 28.8 kWh

The result indicates that there will be approximately 28% battery capacity or 20 km distance left after Friday ends. An uninterrupted 6-hour charge on Saturday and Sunday shall be enough to fill the battery to 100% capacity, leaving the electric car ready to be used for the upcoming week. The following is the calculation involved

EV charger model = Single phase 3.68 kW
Average charging speed = 19 km/h
Distance left in the car = 20 km
Charging time from 0% to 100% = 11 h 45 min

$$\text{Charging time from 20 km to 220 km} = \frac{220\ km\ - 20\ km}{19\ km/h} = 10.5\ h$$

On average, the electric car needs to be plugged in for at least 10 hours and 30 minutes to be charged fully after the previously mentioned driving pattern. In reality, it might take a bit longer as the charging speed of a battery electric vehicle usually decreases once the battery capacity reaches 90%. Having that said, the 12 hours weekend charging time can be adjusted and/or extended to suit the driver's needs. The following is a summary of the new charging pattern.

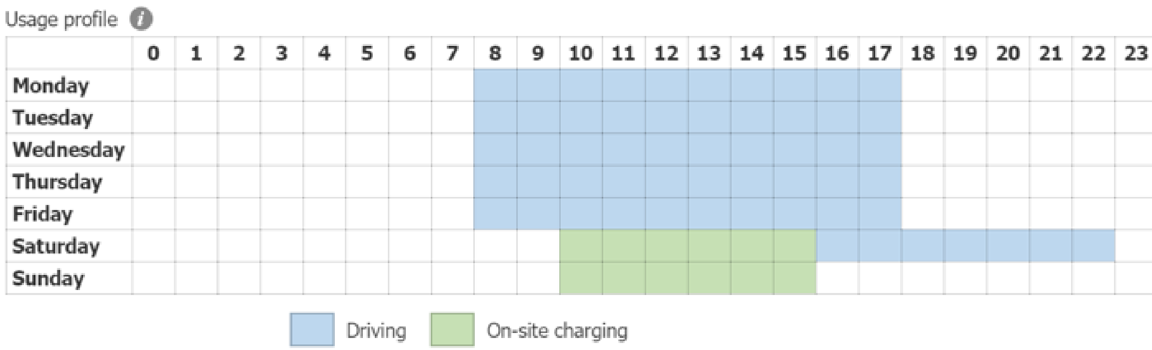


Figure 18: New EV charging pattern

These data are then applied to the regression recommendation algorithm. Precautionary is taken to avoid using the loads during peak hour with energy from the grid. All electrical loads should be powered with as much electrical energy from the PV system as possible.

The following is a flowchart of the Smart Energy Management. Through an application, the calculated result may be sent as a notification and accessible on a smartphone, tablet, computer or any other internet accessible devices.

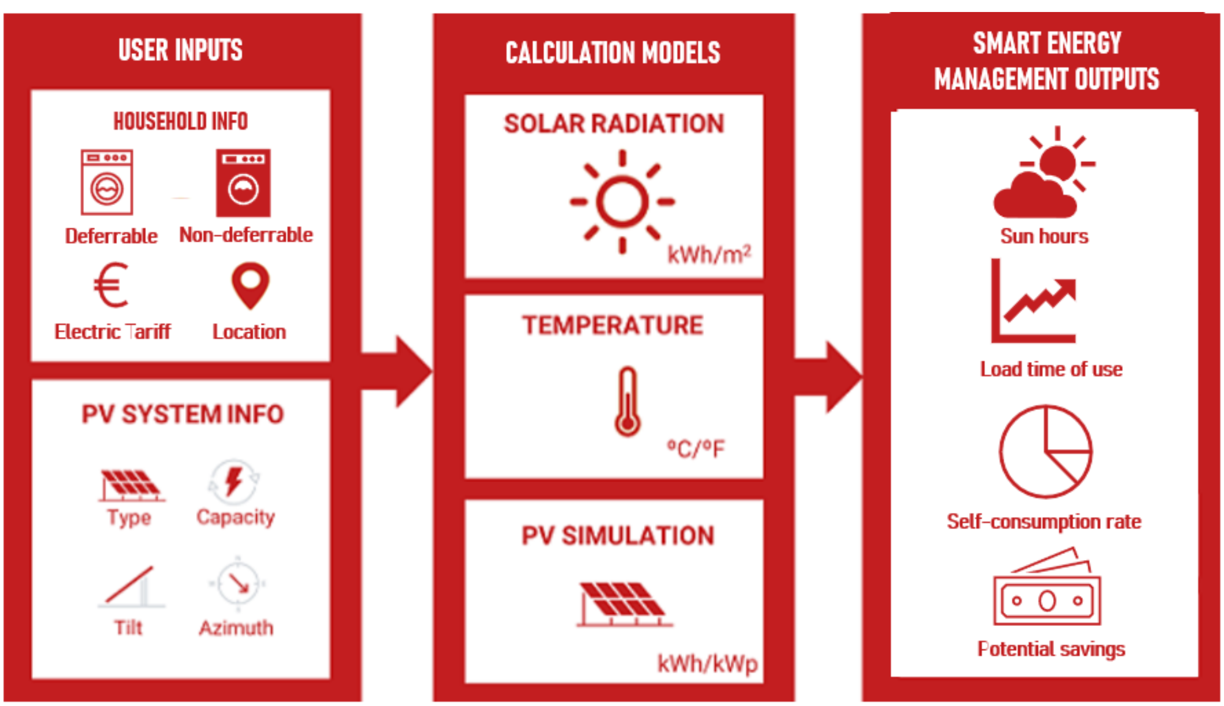


Figure 19: Flowchart of the Smart Energy Management

6.1.4 Output Result

The output demonstrates the sun hours to the user and subsequently the recommended load time of use. As shown in the figure below, the system has distributed the loads according to the sun hours received based on the roof orientation. Peak sun hours is identified with the weather condition logo located on the top. The recommended load time of use is seen on the horizontal bars on the bottom.

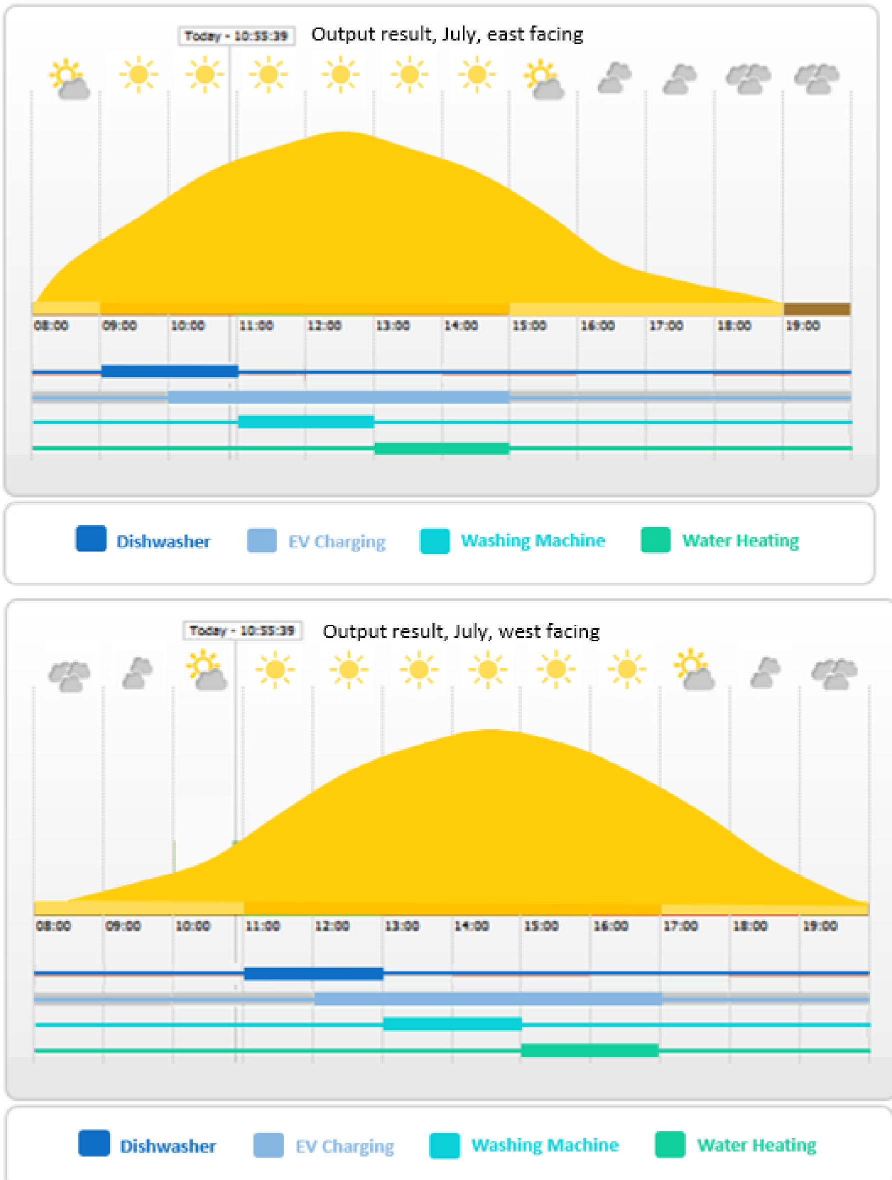


Figure 20: Sun hours and recommended load time of use

As the system recommends the appropriate load time of use, it is ultimately up to the user themselves whether to follow it or not. Keeping in mind that the end goal of the system is to maximise savings, it is plausible that the user would argue with the recommendation given, provided that the calculation is correct. After all, the main motivation of having a PV system is to save money. The figure below summarises the feedback of the energy ecosystem regarding the energy ecosystem to the user.

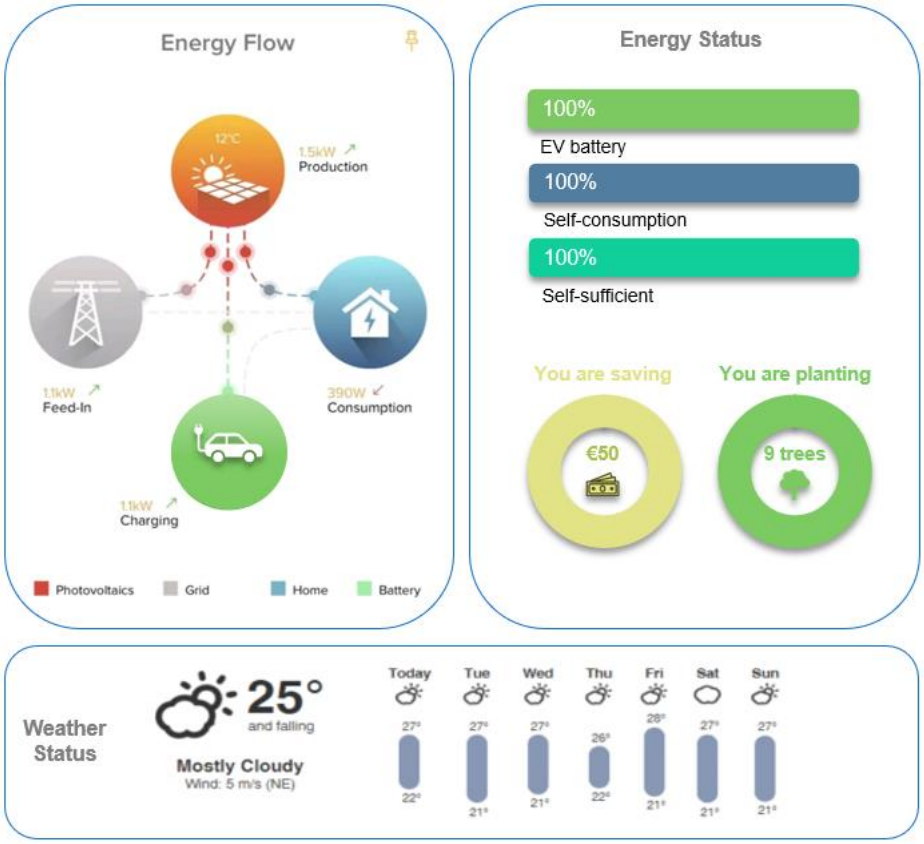


Figure 21: Overall view of the Smart Energy Management

The software shall highlight the difference in the energy status. This is where the user will get a live feedback on how their actual consumption compares to the recommended consumption.

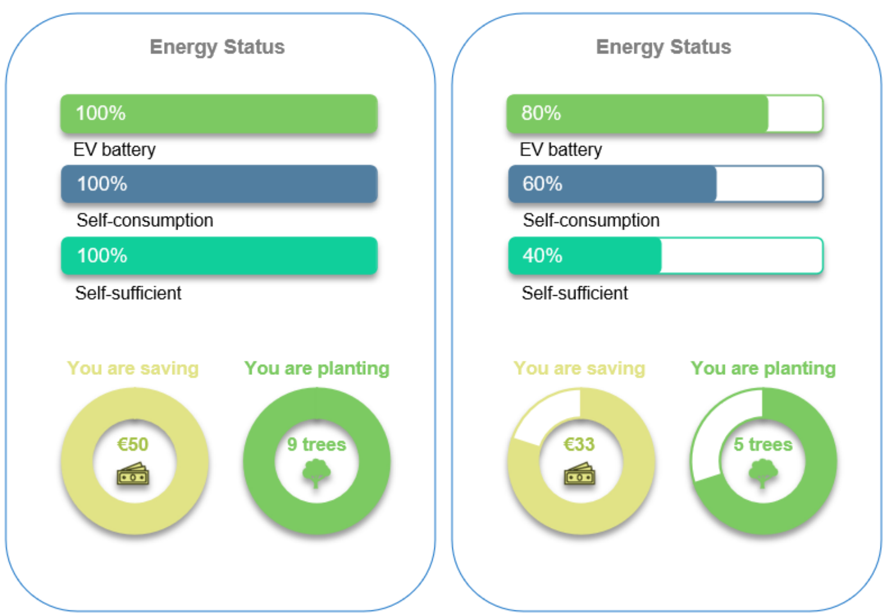


Figure 22: Live feedback, recommended vs actual energy status

6.2 Energy Ecosystem with Smart Energy Management Simulation Result

The solar energy generated accounts 37.8% of the household's electrical energy consumption. On a one-to-one comparison with the standalone ecosystem, there is an increase of 67.1% of the self-consumption uptake from 1856 kWh to 3102 kWh. On a more positive note, the PV system now contributes 65% to the car's electrical energy requirement. The payback time has been reduced to 8.8 years, saving no less than €20000 of electricity bill over the period of 25 years. This translates to nearly €7500 in savings, enough to buy another PV system. The internal rate of return of the PV system is now 11.8% - considerably higher than before.

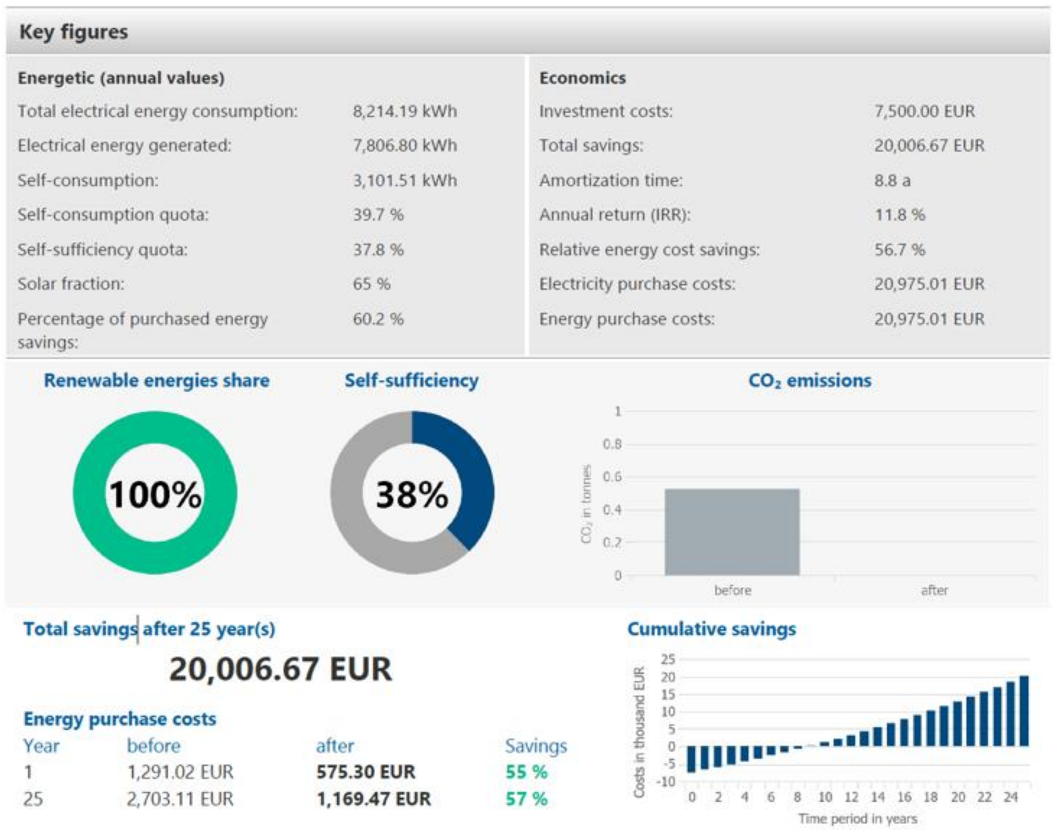


Figure 23: Energetic and economic summary of the PV system with smart energy management

7. Discussion

The following table is a detailed comparison report of the three system designs. Original is the standalone PV system, Alternative 1 is with smart energy management, Alternative 2 is with battery.

	Original	Alternative 1	Alternative 2
Energy system			
Status	✓	✓	✓
PV inverter	1 x SB5.0-1AV-41	1 x SB5.0-1AV-41	1 x SB5.0-1AV-41
PV arrays	16 x Sharp ND-AH330H 5.28 kWp	16 x Sharp ND-AH330H 5.28 kWp	16 x Sharp ND-AH330H 5.28 kWp
Battery inverter			1 x Sunny Boy Storage 5.0-10 Self-consumption increase
Battery			BYD, Battery-Box H6.4, 6.40 kWh
Thermal components	Heat pump 4 kW	Heat pump 4 kW	Heat pump 4 kW
Electrical energy requirement of the load profiles	3,487.00 kWh	3,487.00 kWh	3,487.00 kWh
Heating energy requirement	5,172 kWh	5,172 kWh	5,172 kWh
Hot water requirement	84 l/d	84 l/d	84 l/d
Key figures			
Entire system			
Investment costs	7,500.00 EUR	7,500.00 EUR	12,500.00 EUR
Total savings	12,538.07 EUR	20,006.67 EUR	13,094.63 EUR
Amortization time	11.6 a	8.8 a	14.5 a
Annual return (IRR)	8.2 %	11.8 %	5.7 %
Relative energy cost savings	50.8 %	56.7 %	64.9 %
Energy purchase costs	19,395.91 EUR	20,975.01 EUR	13,839.35 EUR
Percentage of purchased energy savings	50.5 %	60.2 %	65.8 %
Utility grid			
Electricity purchase costs	19,395.91 EUR	20,975.01 EUR	13,839.35 EUR
Electricity			
Total electrical energy consumption	8,214.20 kWh	8,214.19 kWh	8,405.51 kWh
Electrical energy generated	7,806.80 kWh	7,806.80 kWh	7,806.80 kWh
Self-sufficiency quota	22.6 %	37.8 %	47.7 %
PV system			
Self-consumption	1,856.35 kWh	3,101.51 kWh	4,005.79 kWh
Self-consumption quota	23.8 %	39.7 %	51.3 %
Mobility			
Solar fraction	0 %	65 %	0 %

Table 8: System design comparison

The following is the interior visualization of the residential energy ecosystem. It details the connection point of each system.

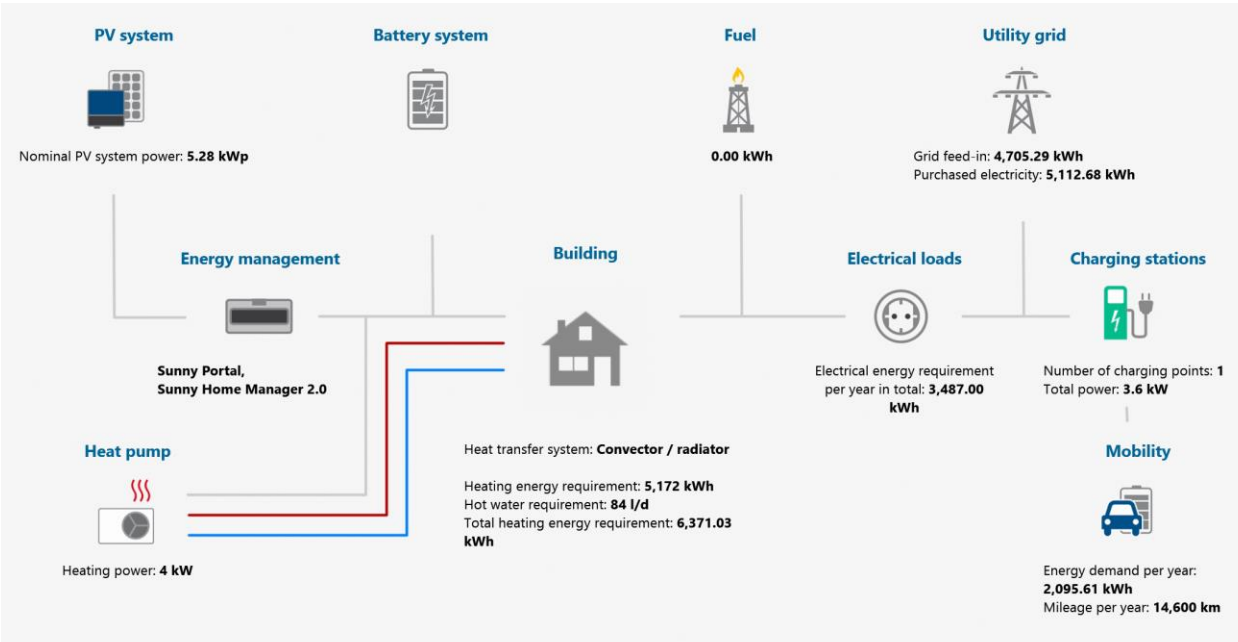
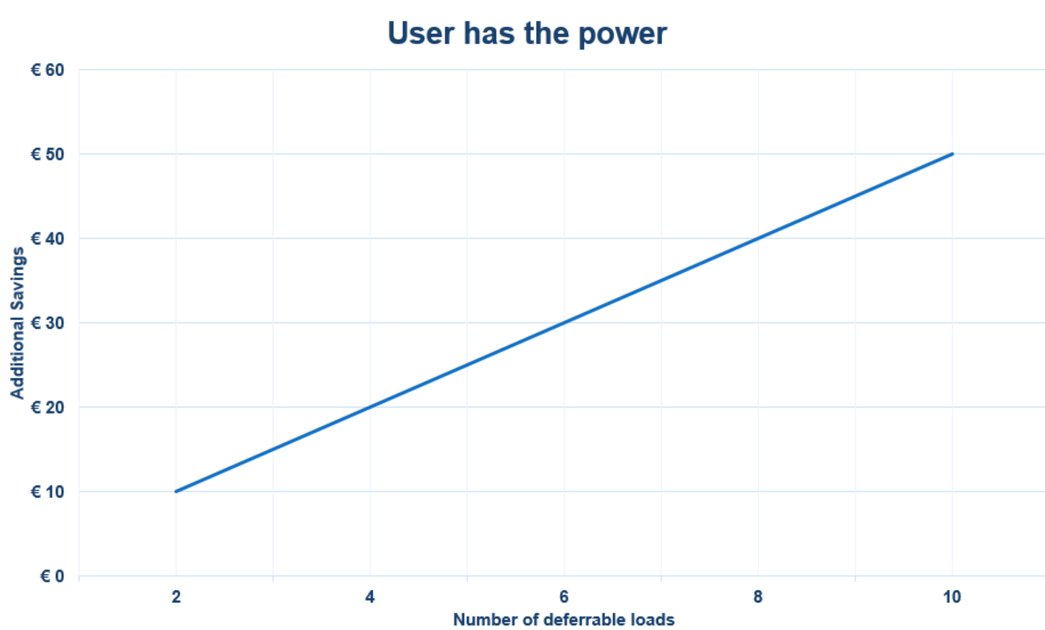


Figure 24: Interior visualization of the energy ecosystem

In comparison, the energy ecosystem with Smart Energy Management system is, by far, the most attractive solution for a typical household. Although the system has not been able to surpass the ecosystem with battery in terms of energetic performance, its profitability certainly overshadows the latter. In fact, the potential of this system does not end there. The household (or the user) has the ultimate power in determining the profitability of the system. That is, theoretically speaking the relationship between the savings and the user-defined number of deferrable loads is linear. The higher the number of loads being defined as deferrable, the higher the potential savings can be achieved.



Graph 1: Theoretical linear relation between deferrable loads and savings

8. Conclusion

This paper has presented, through high level simulations based on real world parameters, a feasible method to Achieve Zero Carbon Lifestyle within the Residential Energy Ecosystem. Results have shown that households going full electric coupled with an electric car will help to decarbonise energy related CO_2 emissions and limit the average global temperature rise to well below 2°C.

Recent research on citizen's drawback towards the decarbonisation transition revolves around economic factors. Current findings in this paper have suggested that these technologies represent a major investment that must be proven to increase the household's energy savings and reduce their exposure to volatile electricity prices. Government subsidies and policies have provided a much needed push for households to reduce their carbon emission. Nonetheless, the sky-high price of electricity does not justify the cost of owning such all-electric residential energy ecosystem – if not done correctly. A solution based on intelligent systems as seen in this paper has been proven to increase the potential savings. Moreover, it should not require additional investment as the software can be integrated within the PV inverter's operating system as a performance optimizer.

The Smart Energy Management system has successfully bridged the gap between consumers and energy, letting households manage their consumption based on user-determined inputs and receive alerts about the best time to utilise their deferrable loads. The system's high level of customizability and active user participation encouragement helps to increase solar energy self-consumption rate. While the successful rate of the system relies almost entirely on the user, it eliminates the anonymity between the user and the "invisible" energy. In the future, more rigorous research on methods to improve the user's adherence to the recommendation algorithm could help to improve the system's credibility.

I learned that despite the findings in this paper covers the average household energy consumption in the region, majority of the houses in Catalonia are apartments inside a building block. Consequently, it is more challenging to design such effective residential energy ecosystem for a block of apartments. It is therefore an area that I wish to focus on in the future if the opportunity arises. I passionately believe in expanding the findings in this paper into a scalable application for said households.

At the end of the day, the global energy transition also involves the transition from a centralized, oligopolistic electricity market into a decentralized, distributed electricity market. This means that more power is given to the end consumer compared to before.

Last but not least, the unfavourable feed in tariff compensation must be amended if the government would like more households to adopt this zero carbon lifestyle. The citizens are very well aware of the favourable hours of sun that can be harvested to power their needs. Many have long fought for an either lower purchasing price or a higher feed in tariff compensation. A mere 0.05€ compensation per kWh is certainly considered as peanuts when compared to the 0.15€ purchasing price per kWh. This is an important element discovered in my findings as it decisively influences the payback period of a PV system. An element that is untouchable for a renewable energy advocator like me.

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Annex

Compare alternatives

Project: Energy Management **Location: Spain / Barcelona**

	Original	Alternative 1	Alternative 2
Energy system			
Status			
PV inverter	1 x SB5.0-1AV-41	1 x SB5.0-1AV-41	1 x SB5.0-1AV-41
PV arrays	16 x Sharp ND-AH330H 5.28 kWp	16 x Sharp ND-AH330H 5.28 kWp	16 x Sharp ND-AH330H 5.28 kWp
Battery inverter			1 x Sunny Boy Storage 5.0-10 Self-consumption increase
Battery			BYD, Battery-Box H6.4, 6.40 kWh
Thermal components	Heat pump 4 kW	Heat pump 4 kW	Heat pump 4 kW
Electrical energy requirement of the load profiles	3,487.00 kWh	3,487.00 kWh	3,487.00 kWh
Heating energy requirement	5,172 kWh	5,172 kWh	5,172 kWh
Hot water requirement	84 l/d	84 l/d	84 l/d
Key figures			
Entire system			
Investment costs	7,500.00 EUR	7,500.00 EUR	12,500.00 EUR
Total savings	12,538.07 EUR	20,006.67 EUR	13,094.63 EUR
Amortization time	11.6 a	8.8 a	14.5 a
Annual return (IRR)	8.2 %	11.8 %	5.7 %
Relative energy cost savings	50.8 %	56.7 %	64.9 %
Energy purchase costs	19,395.91 EUR	20,975.01 EUR	13,839.35 EUR
Percentage of purchased energy savings	50.5 %	60.2 %	65.8 %
Utility grid			
Electricity purchase costs	19,395.91 EUR	20,975.01 EUR	13,839.35 EUR
Electricity			
Total electrical energy consumption	8,214.20 kWh	8,214.19 kWh	8,405.51 kWh
Electrical energy generated	7,806.80 kWh	7,806.80 kWh	7,806.80 kWh
Self-sufficiency quota	22.6 %	37.8 %	47.7 %
PV system			
Self-consumption	1,856.35 kWh	3,101.51 kWh	4,005.79 kWh
Self-consumption quota	23.8 %	39.7 %	51.3 %
Mobility			
Solar fraction	0 %	65 %	0 %

Project: Energy Management

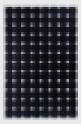
Project number: ---

Location: Spain / Barcelona

Grid voltage: 230V (230V / 400V)

System overview

PV arrays



16 x Sharp ND-AH330H (09/2018) (Area 1 (South))

Azimuth angle: 0 °, Tilt angle: 20 °, Mounting type: Roof, Peak power: 5.28 kWp

PV inverter

1 x SMA SB5.0-1AV-41

Energy management

Sunny Home Manager 2.0

Sunny Portal

Notes:

Signature

*Important: The yield values displayed are estimates. They are determined mathematically. SMA Solar Technology AG accepts no responsibility for the real yield value which can deviate from the yield values displayed here. Reasons for deviations are various external conditions, such as soiling of the PV modules or fluctuations in the efficiency of the PV modules.

Your energy system at a glance

Project:	Energy Management
Project number:	---
Location:	Location: Spain / Barcelona
Date:	6/2/2020

Created with Sunny Design 5.0.1.R

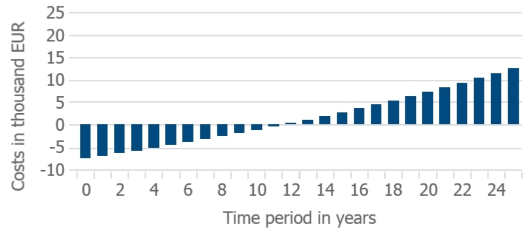
Total savings after 25 year(s)

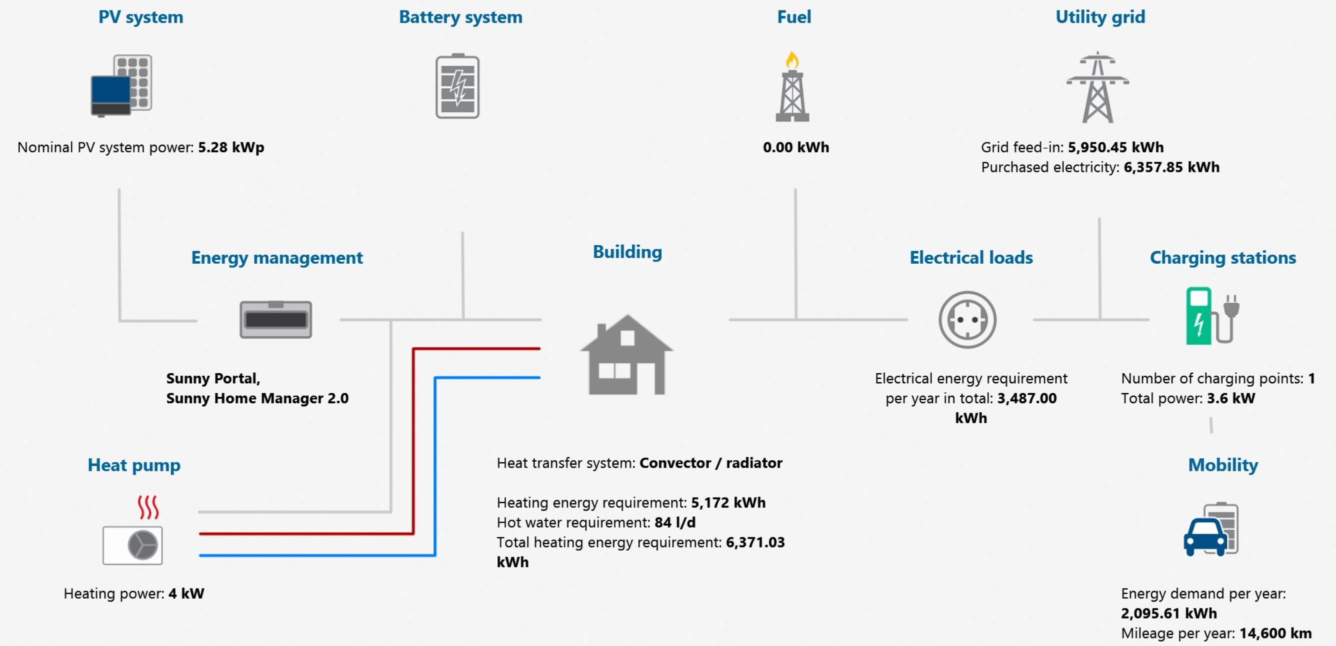
12,538.07 EUR

Energy purchase costs

Year	before	after	Savings
1	1,050.09 EUR	**531.99 EUR**	**49 %**
25	2,198.65 EUR	**1,081.42 EUR**	**51 %**

Cumulative savings



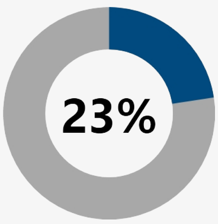


Details	
Investment costs	**7,500.00 EUR**
Grant amount	**---**
Net present value	**131.45 EUR**
Annual return (IRR)	**8.2 %**
Amortization time	**11.6 a**

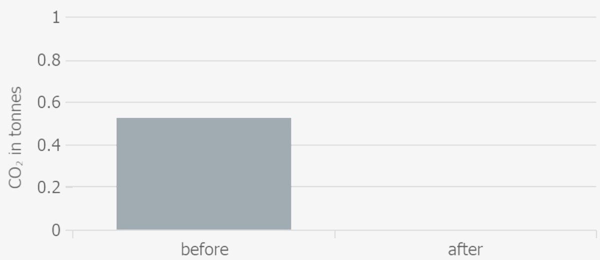
Energy	before	after	Savings
Total electrical energy consumption	3,487.00 kWh	**8,214.20 kWh**	**-136 %**
Total fuel energy consumption	5,172.00 kWh	**0.00 kWh**	**100 %**
Self-consumption		**1,856.35 kWh**	
Grid feed-in		**5,950.45 kWh**	

Renewable energies share

Self-sufficiency



CO_2 emissions



*Important: The yield values displayed are estimates. They are determined mathematically. SMA Solar Technology AG accepts no responsibility for the real yield value which can deviate from the yield values displayed here. Reasons for deviations are various external conditions, such as soiling of the PV modules or fluctuations in the efficiency of the PV modules.

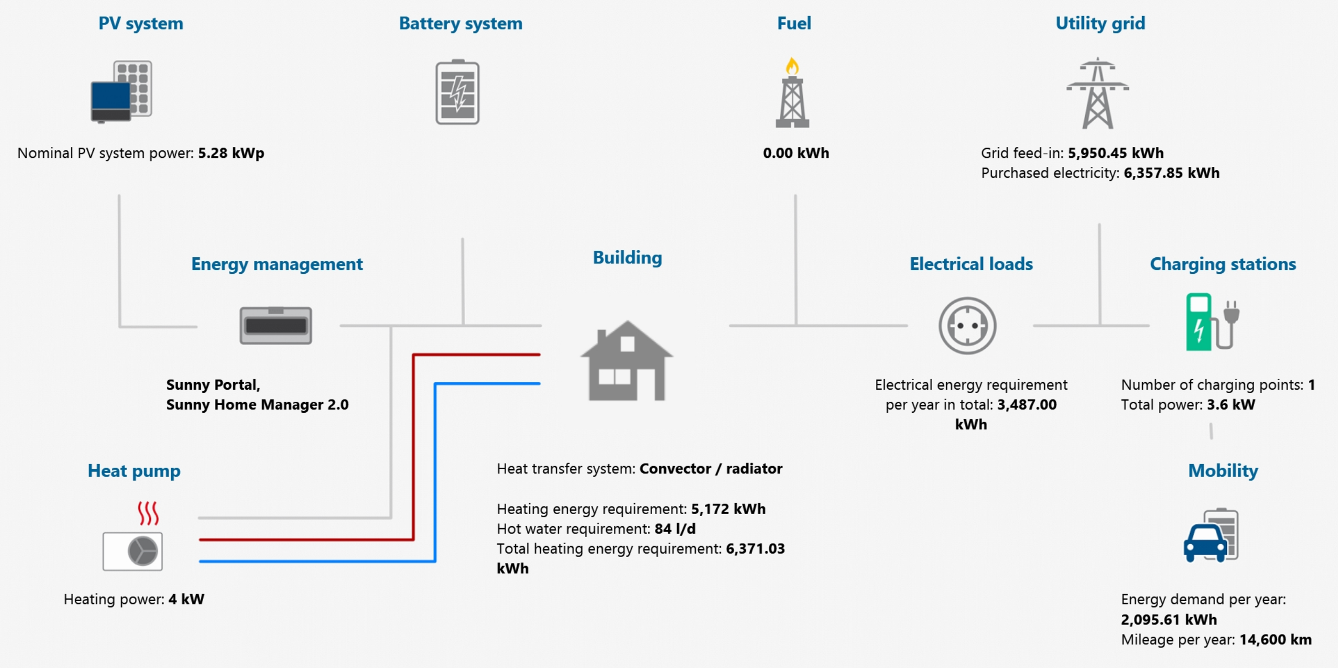
Energy system

Project name: Energy Management

Project number:

Location: Spain / Barcelona

Energy system schematic



Key figures

Energetic (annual values)		Economics	
Total electrical energy consumption:	8,214.20 kWh	Investment costs:	7,500.00 EUR
Electrical energy generated:	7,806.80 kWh	Total savings:	12,538.07 EUR
Self-consumption:	1,856.35 kWh	Amortization time:	11.6 a
Self-consumption quota:	23.8 %	Annual return (IRR):	8.2 %
Self-sufficiency quota:	22.6 %	Relative energy cost savings:	50.8 %
Solar fraction:	0 %	Electricity purchase costs:	19,395.91 EUR
Percentage of purchased energy savings:	50.5 %	Energy purchase costs:	19,395.91 EUR

PV design data

Total number of PV modules:	16	AC active power:	5.00 kW
Peak power:	5.28 kWp	Active power ratio:	94.7 %
Number of PV inverters:	1	Energy usability factor:	100 %
Nominal AC power of the PV inverters:	5.00 kW	Unbalanced load:	5.00 kVA

The displayed results are approximate values to give a general indication to users of possible operating results. The results are determined mathematically. The actual operating results will be dictated significantly by the actual climatic conditions, the actual efficiency, the system components' operating conditions and the individual consumption behavior and can deviate from the calculated results. SMA Solar Technology AG therefore assumes no liability in the event of deviations between the calculated and actual operating results.

Inverter designs

Project: Energy Management
Project number:

Subproject Subproject 1

Location: Spain / Barcelona
Ambient temperature:
Annual extreme low temperature: -1 °C
Average high Temperature: 24 °C
Annual extreme high temperature: 33 °C

1 x SMA SB5.0-1AV-41 (PV system section 1)

Peak power:	5.28 kWp
Total number of PV modules:	16
Number of PV inverters:	1
Max. DC power (cos φ = 1):	5.25 kW
Max. AC active power (cos φ = 1):	5.00 kW
Grid voltage:	230V (230V / 400V)
Nominal power ratio:	99 %
Dimensioning factor:	105.6 %
Displacement power factor cos φ:	1
Full load hours:	1604.6 h

SMA SB5.0-1AV-41

PV design data

Input A: Area 1 (South)
8 x Sharp ND-AH330H (09/2018), Azimuth angle: 0 °, Tilt angle: 20 °, Mounting type: Roof

Input B: Area 1 (South)
8 x Sharp ND-AH330H (09/2018), Azimuth angle: 0 °, Tilt angle: 20 °, Mounting type: Roof

	Input A:	Input B:
Number of strings:	1	1
PV modules:	8	8
Peak power (input):	2.64 kWp	2.64 kWp
Typical PV voltage:	✓ 275 V	✓ 275 V
Min. PV voltage:	257 V	257 V
Min. DC voltage (Grid voltage 230 V):	100 V	100 V
Max. PV voltage:	✓ 401 V	✓ 401 V
Max. DC voltage:	600 V	600 V
Max. MPP current of PV array:	✓ 8.7 A	✓ 8.7 A
Max. operating input current per MPPT:	15 A	15 A
Max. input short-circuit current per MPPT:	20 A	20 A
Photovoltaic Output Circuit Current:	✓ 9.3 A	✓ 9.3 A

PV/Inverter compatible

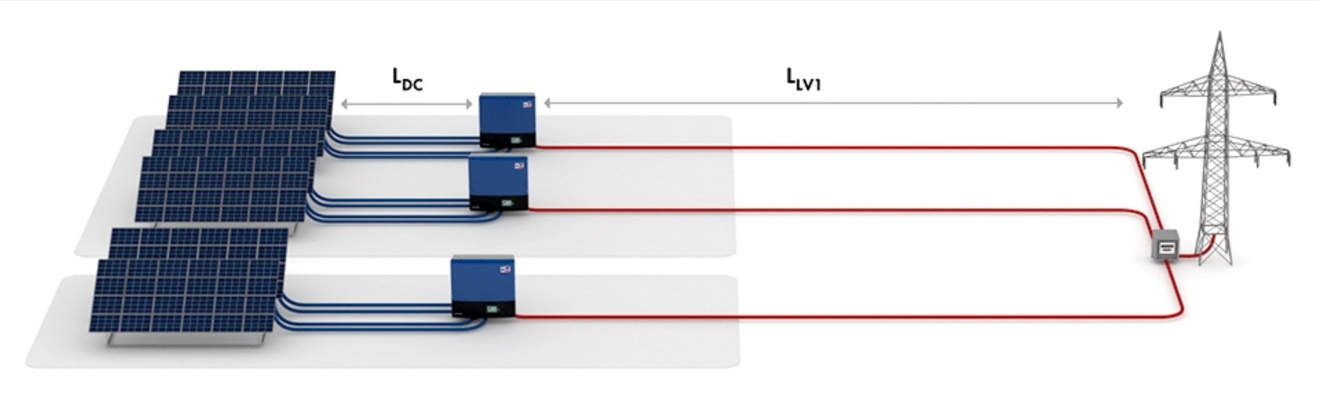
Cable sizing

Project name: Energy Management **Location: Spain / Barcelona**
Project number:

Overview

	DC	LV	Total
Power loss at nominal operation	14.75 W	40.64 W	55.39 W
Rel. power loss at rated nominal operation	0.28 %	0.81 %	1.09 %
Total cable length	40.00 m	10.00 m	50.00 m
Cable cross-sections	4 mm²	4 mm²	4 mm²

Graphic



DC cables

		Cable material	Single length	Cross section	Voltage drop	Rel. power loss
Subproject 1						
1 x SMA SB5.0-1AV-41 PV system section 1	A	Copper	10.00 m	4 mm²	796.4 mV	0.28 %
	B	Copper	10.00 m	4 mm²	796.4 mV	0.28 %

Cables LV1

	Cable material	Single length	Cross section	Cable resistance	Rel. power loss
Subproject 1					
1 x SMA SB5.0-1AV-41 PV system section 1	Copper	10.00 m	4 mm²	R: 86.000 mΩ XL: 1.500 mΩ	0.81 %

The displayed results are approximate values to give a general indication to users of possible operating results. The results are determined mathematically. The actual operating results will be dictated significantly by the actual climatic conditions, the actual efficiency, the system components' operating conditions and the individual consumption behavior and can deviate from the calculated results. SMA Solar Technology AG therefore assumes no liability in the event of deviations between the calculated and actual operating results.

Design energy management

Project name: Energy Management
Project number:

Location: Spain / Barcelona

PV system	System Monitoring	
Subproject 1	**Within the PV system**	**External**
1 x SMA SB5.0-1AV-41 PV system section 1	**Sunny Home Manager 2.0** The control center with integrated measuring system for smart energy management	**Sunny Portal** Internet portal for monitoring PV systems and for the visualization and presentation of PV system data

Information	
Sunny Home Manager 2.0	For the implementation of the storage management and the limitation of the active power feed-in, the internal measuring system of the Sunny Home Manager 2.0 for measuring the grid feed-in and purchased electricity, must have been connected and configured (see planning guidelines "SMA Smart Home").

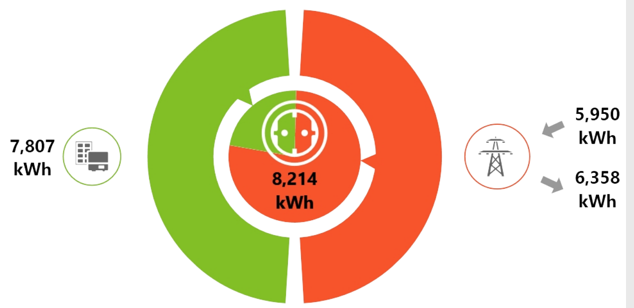
Results energy

Project name: Energy Management
Project number:

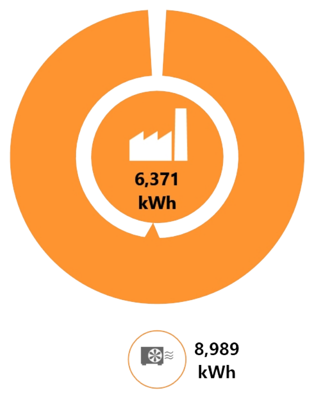
Location: Spain / Barcelona

Energy balance (annual values)

Electricity



Thermal



Results (annual values)

Entire system	**before**	**after**
Total energy consumption	10,754.61 kWh	14,585.23 kWh
Renewable energies share	---	100.0 %
Generated renewable energy		14,171.04 kWh
Total purchased energy	12,850.22 kWh	6,357.85 kWh
CO_2 emissions	0.52 t	0.00 t
CO_2 reduction		100 %
Percentage of purchased energy savings		50.5 %
Utility grid		
Grid feed-in		5,950.45 kWh
Purchased electricity	5,582.61 kWh	6,357.85 kWh
Purchased electricity savings		-13.9 %
Electricity		
Total energy requirement	3,487.00 kWh	8,214.20 kWh
Total electrical energy consumption	3,487.00 kWh	8,214.20 kWh
Electrical energy generated		7,806.80 kWh
Self-consumption		1,856.35 kWh
Self-consumption quota		23.8 %
Self-sufficiency quota		22.6 %
Max. purchased electricity power	7.66 kW	6.46 kW
Reduction of the purchased power peak		1.20 kW
Utilization time	729 h	985 h
CO_2 emissions	0.00 t	0.00 t
CO_2 reduction		0 %

Generated renewable energy		7,806.80 kWh
Renewable energies share	100.0 %	100.0 %
Fuel		
Total fuel energy consumption	5,172.00 kWh	0.00 kWh
Fuel savings		100 %
CO_2 emissions	---	0.00 t
CO_2 reduction		100 %
Thermal		
Total heating energy requirement	5,172.00 kWh	6,371.03 kWh
Heating energy generated		8,989.21 kWh
Generated renewable energy		6,364.24 kWh
Renewable energies share	---	100.0 %
Mobility		
Mileage		14,600 km
Power consumption		2,095.61 kWh
Power consumption grid		2,095.61 kWh
Solar fraction		0 %
CO_2 emissions	0.52 t	0.00 t
Number of unplanned charges		0
Total energy of all unplanned charges		0.00 kWh
Internally charged energy		2,095.61 kWh
Charging speed		100 %
Total charging duration		587.8 h
Building		
Heating energy requirement		5,171.87 kWh
Energy consumption heating element		7,207.49 kWh
Hot water energy requirement		1,199.16 kWh
Energy consumption hot water		1,781.72 kWh
Electrical loads		
Electrical energy requirement of the load profiles	3,487.00 kWh	3,487.00 kWh
Total energy requirement	3,487.00 kWh	8,214.20 kWh
PV system		
Electrical energy generated		7,806.80 kWh
Specific yield		1479 kWh/kWp
Grid feed-in		5,950.45 kWh
Self-consumption		1,856.35 kWh
Self-consumption quota		23.8 %
Self-sufficiency quota		22.6 %
Heat pump		
Electricity and fuel consumption		2,624.97 kWh
Heating energy generated		8,989.21 kWh
Annual performance factor		3.42

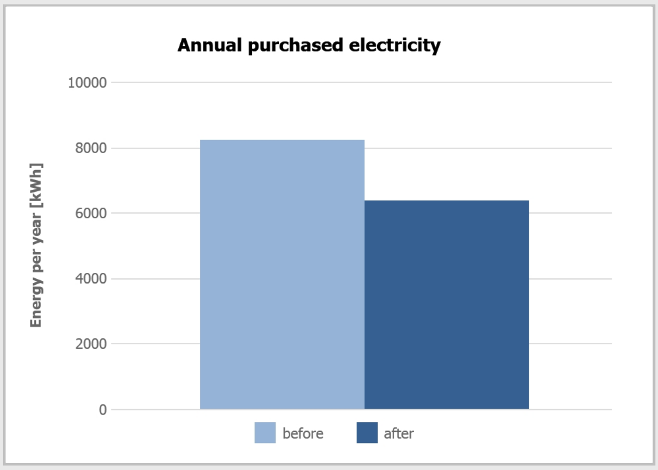
The displayed results are approximate values to give a general indication to users of possible operating results. The results are determined mathematically. The actual operating results will be dictated significantly by the actual climatic conditions, the actual efficiency, the system components' operating conditions and the individual consumption behavior and can deviate from the calculated results. SMA Solar Technology AG therefore assumes no liability in the event of deviations between the calculated and actual operating results.

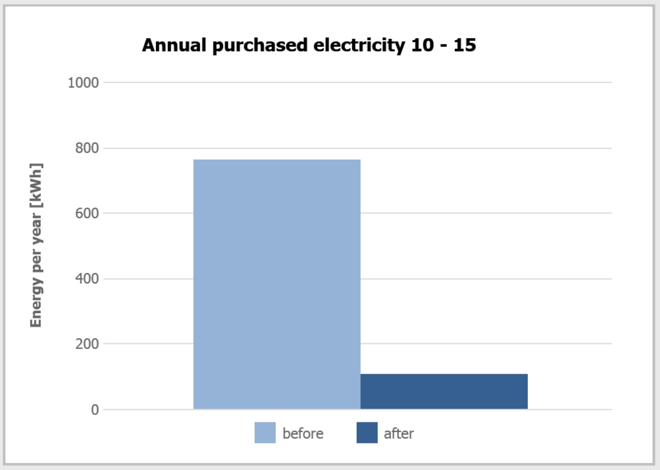
Load analysis

Project: Energy Management
Project number:

Purchased electricity

Electrical energy drawn from the utility grid per year is shown.

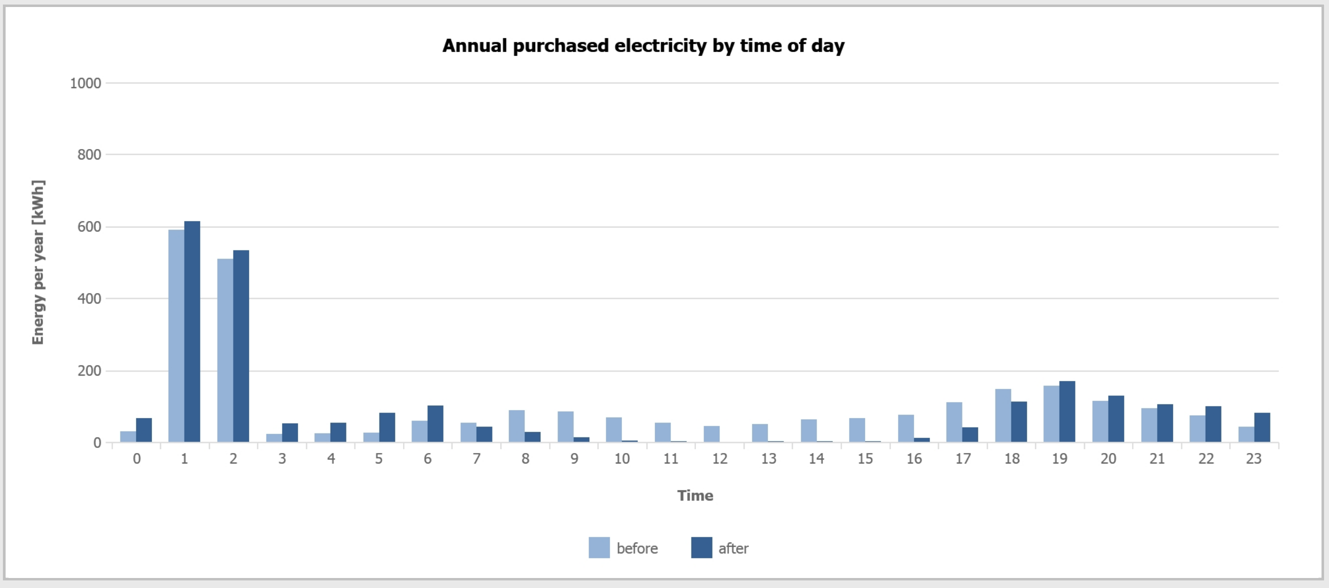




	Annual purchased electricity	Annual purchased electricity 10 - 15
before	8,214 kWh	761 kWh
after	6,358 kWh	106 kWh

Purchased electricity / time of day

Electrical energy drawn from the utility grid depending on the time of day is shown.

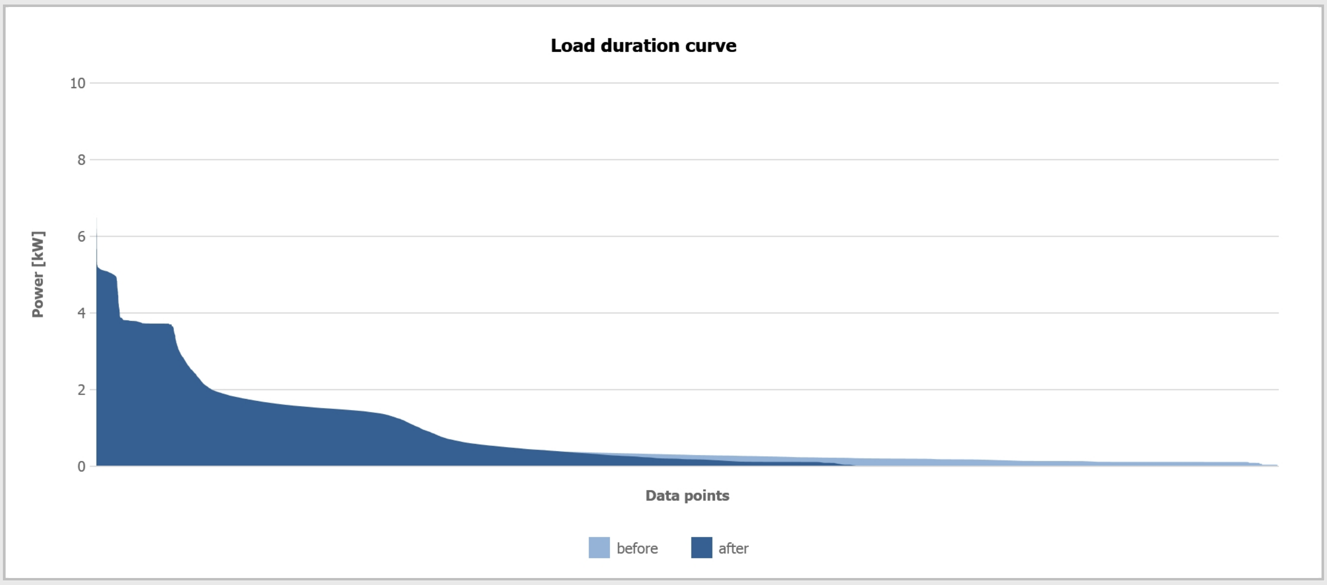


	Annual purchased electricity	April - September
before	8,214 kWh	2,632 kWh
after	6,358 kWh	2,326 kWh

Load analysis

Load duration curve

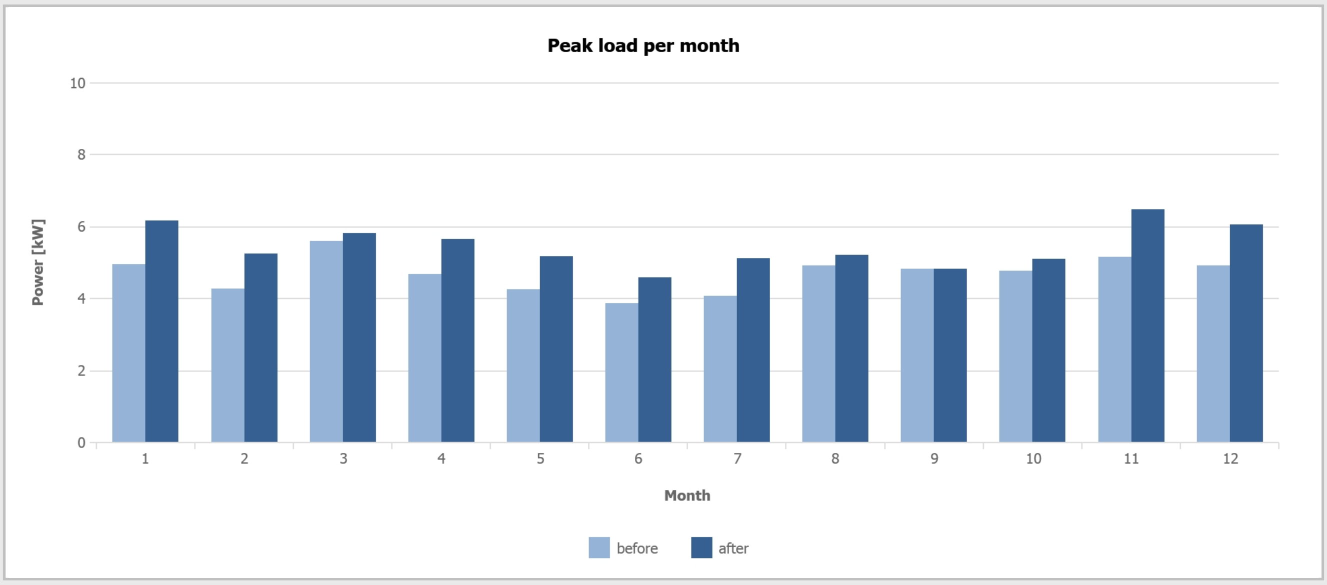
The diagram shows the power drawn from the utility grid as a load duration curve (load profile characteristic curve). The power values for a year are sorted by size. In particular, the diagram provides information on the frequency of the peak load, minimum load, and basic load.



	before	after
Power values above the load limit	---	--- (---)
Maximum power	5.579 kW	6.457 kW
Purchased electricity above the load limit	---	---
Total purchased electricity	8,214 kWh	6,358 kWh

Peak load

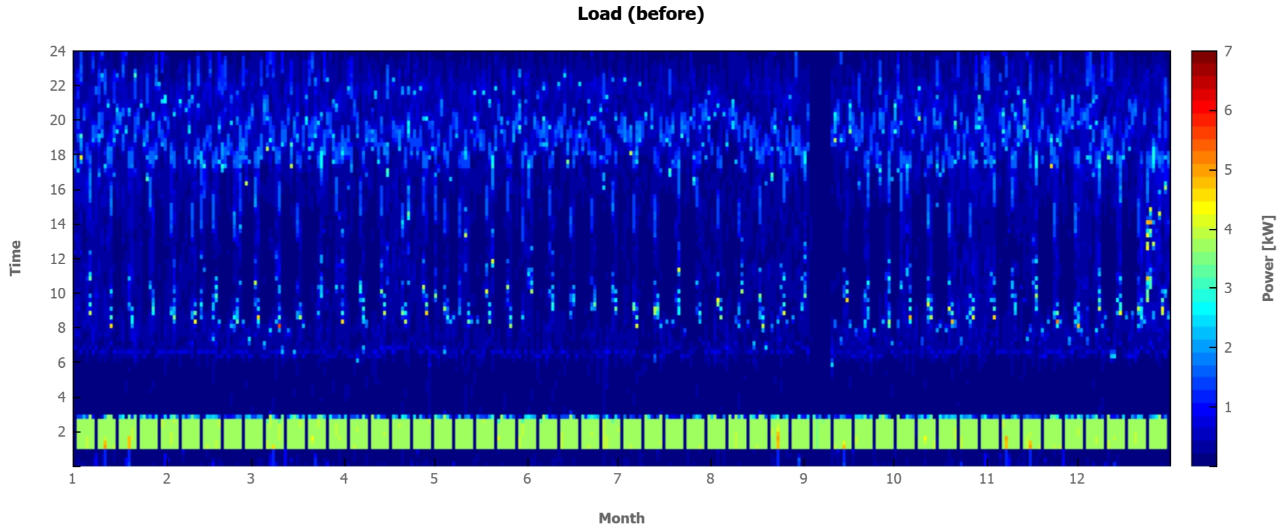
The maximum power per month drawn from the utility grid is shown, the so-called peak load. This peak load is used in some electricity tariffs as the basis for monthly billing.

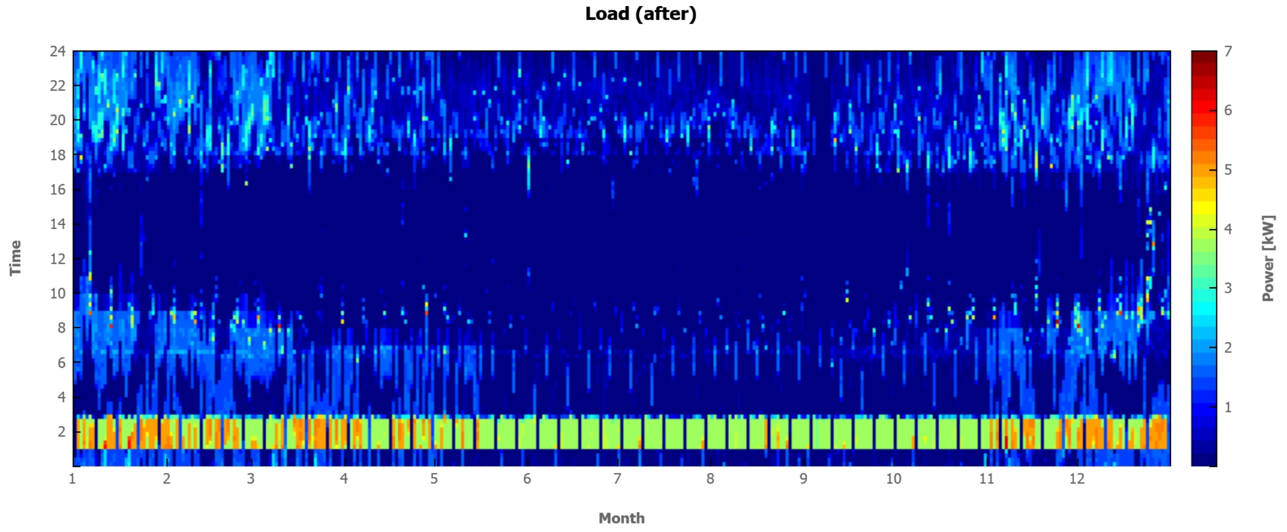


Load analysis

Power chart / load

The power values of one year depending on the time of day (vertical) and date (horizontal) are represented in this so-called heatmap.





The displayed results are estimated values which are derived mathematically. SMA Solar Technology AG accepts no liability for the actual self-consumption which may deviate from the values displayed here. The potential self-consumption essentially depends on individual load patterns, which may deviate from the load profile on which the calculation is based.

Profitability: settings

Project name: Energy Management **Location: Spain / Barcelona**
Project number:

General

The currency is **EUR**
The analysis period of profitability is **25 Years**
The electric current purchasing tariff is **100% Renewable Lucera**
The inflation rate is **3.00 %**
The interest rate is **---**

PV system

The annual fixed costs are **0.00 %** of the investment costs
The service life is **25 Years**
The price change factor is **0 %**
The feed-in tariff for electric current is **PVPC excedentes 2.0**
The grant amount is **---**
The equity ratio is **100 %**
Selected type of credit: **None**
The credit period is **0 Years**
The redemption-free period is **0 Years**
The annual interest rate is **0.0 %**

Heat pump

The annual fixed costs are **0.00 %** of the investment costs
The service life is **25 Years**
The price change factor is **0 %**
The grant amount is **---**
The equity ratio is **100 %**
Selected type of credit: **None**
The credit period is **0 Years**
The redemption-free period is **0 Years**
The annual interest rate is **0.0 %**

Charging stations

The annual fixed costs are **0.00 %** of the investment costs
The service life is **25 Years**
The price change factor is **0 %**
The grant amount is **---**
The equity ratio is **100 %**
Selected type of credit: **None**
The credit period is **0 Years**
The redemption-free period is **0 Years**
The annual interest rate is **0.0 %**

The displayed results are approximate values to give a general indication to users of possible operating results. The results are determined mathematically. The actual operating results will be dictated significantly by the actual climatic conditions, the actual efficiency, the system components' operating conditions and the individual consumption behavior and can deviate from the calculated results. SMA Solar Technology AG therefore assumes no liability in the event of deviations between the calculated and actual operating results.

Results profitability

Project name: Energy Management
Project number:

Location: Spain / Barcelona

Profitability

Electricity costs in the first year

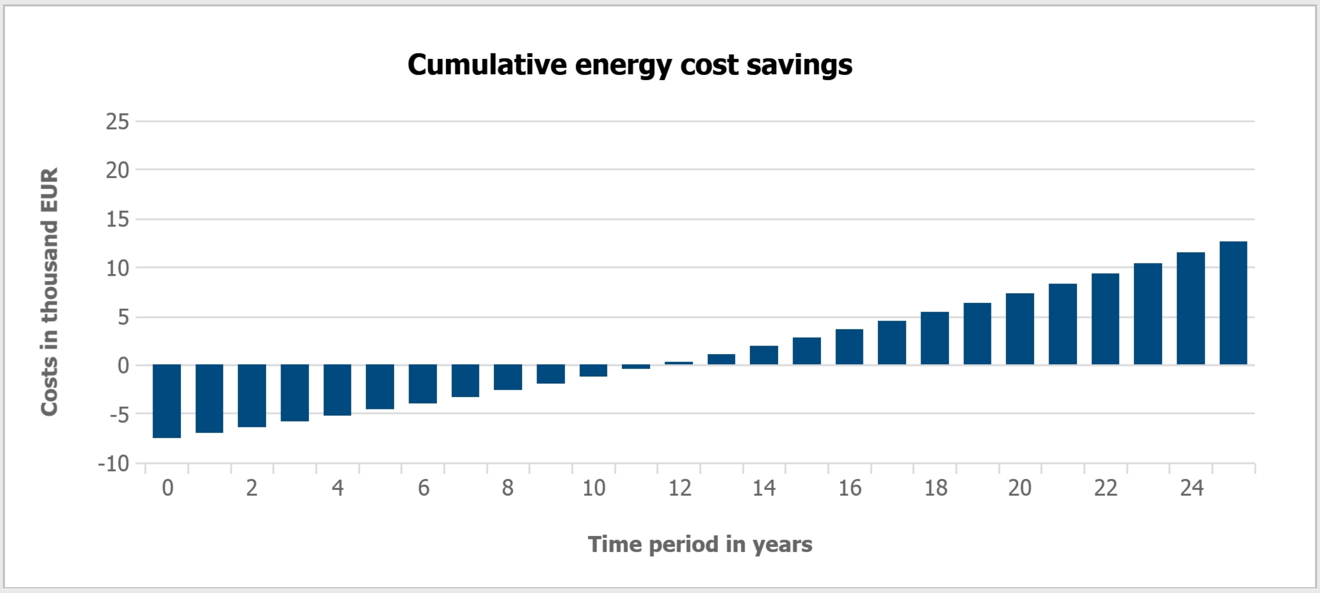
before
741.16 EUR/a

after
531.99 EUR/a

Fuel costs in the first year

before
308.92 EUR/a

after
0.00 EUR/a



Results

Entire system	before	after
Investment costs		7,500.00 EUR
Total energy supply costs		26,895.91 EUR
Total savings		12,538.07 EUR
Energy production costs		0.0426 EUR/kWh
Net present value		131.45 EUR
Amortization time		11.6 a
Amortization time (discounted)		24.2 a
Annual return (IRR)		8.2 %
Operating costs		10.00 EUR
Debt capital		---
Energy purchase costs	39,433.98 EUR	19,395.91 EUR
Residual value		0.00 EUR
Energy cost savings		20,038.07 EUR
Relative energy cost savings		50.8 %
Grant amount		---
Utility grid		
Electricity purchase costs	27,832.96 EUR	19,395.91 EUR

Specific electricity purchase costs	0.21255 EUR/kWh	0.08367 EUR/kWh
Feed-in tariff		0.00 EUR
Fuel		
Fuel costs	11,601.02 EUR	0.00 EUR
Avoided fuel costs		11,601.02 EUR
Thermal		
Heating costs	11,601.02 EUR	0.00 EUR
Specific heating costs	0.05 EUR/kWh	0.00 EUR/kWh
Heating cost savings		11,601.02 EUR
Relative heating cost savings		100 %
Mobility		
Energy costs	39.19 EUR	10,422.64 EUR
Relative energy costs	0.01 EUR/100 km	1.96 EUR/100 km
Savings		-10,383.45 EUR
PV system		
Investment costs		7,500.00 EUR
Specific investment costs		1,420.45 EUR/kWp
Energy production costs		0.0937 EUR/kWh
Operating costs		10.00 EUR
Residual value		0.00 EUR
Debt capital		---
Feed-in tariff		0.00 EUR
Grant amount		---
Heat pump		
Investment costs		0.00 EUR
Specific investment costs		0.00 EUR/kW
Energy production costs		0.0000 EUR/kWh
Operating costs		0.00 EUR
Residual value		0.00 EUR
Debt capital		---
Grant amount		---
Charging stations		
Yield from vehicle charge		0.00 EUR
Costs from vehicle charge		0.00 EUR
Investment costs		0.00 EUR
Operating costs		0.00 EUR
Debt capital		---
Grant amount		---
Residual value		0.00 EUR

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Project: **Energy Management**

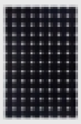
Project number: ---

Location: Spain / Barcelona

Grid voltage: 230V (230V / 400V)

System overview

PV arrays



16 x Sharp ND-AH330H (09/2018) (Area 1 (South))

Azimuth angle: 0 °, Tilt angle: 20 °, Mounting type: Roof, Peak power: 5.28 kWp

PV inverter

1 x SMA SB5.0-1AV-41

Energy management

Sunny Home Manager 2.0

Sunny Portal

Notes:

Signature

*Important: The yield values displayed are estimates. They are determined mathematically. SMA Solar Technology AG accepts no responsibility for the real yield value which can deviate from the yield values displayed here. Reasons for deviations are various external conditions, such as soiling of the PV modules or fluctuations in the efficiency of the PV modules.

Your energy system at a glance

Project:	Energy Management
Project number:	---
Location:	Location: Spain / Barcelona
Date:	6/2/2020

Created with Sunny Design 5.0.1.R

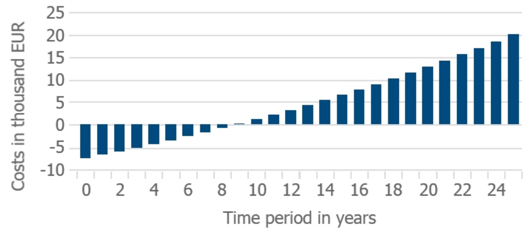
Total savings after 25 year(s)

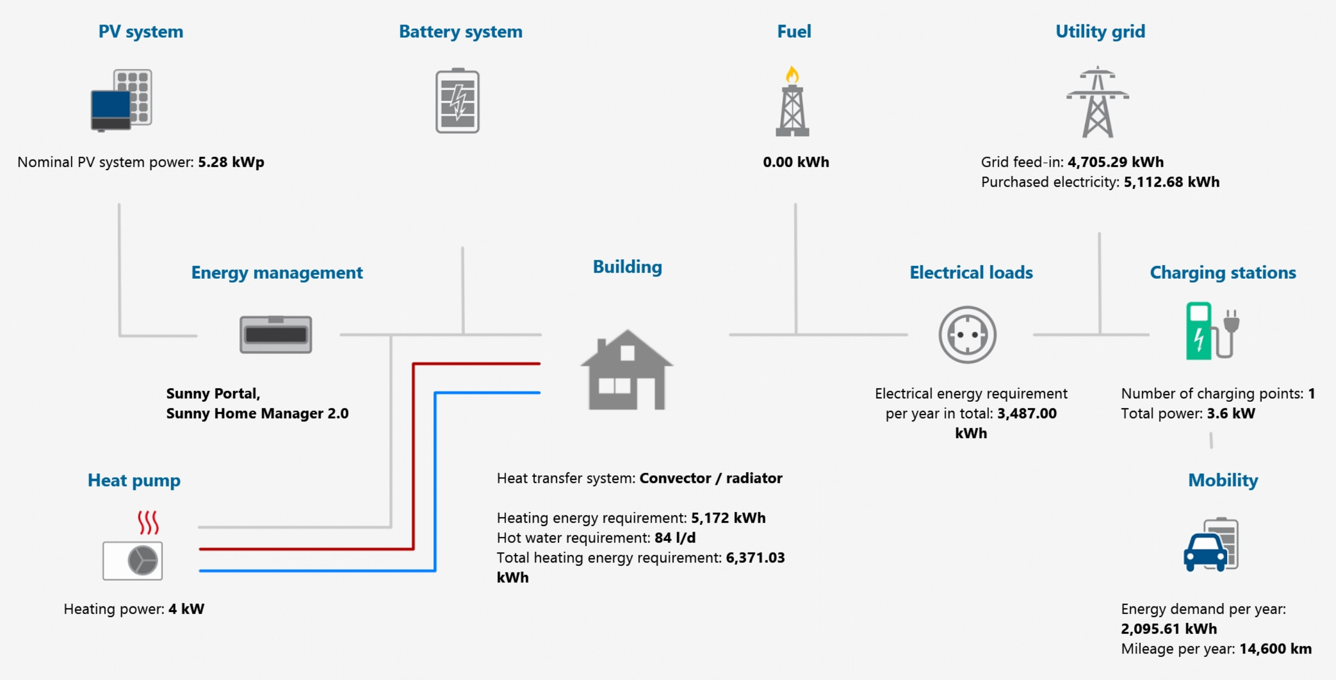
20,006.67 EUR

Energy purchase costs

Year	before	after	Savings
1	1,291.02 EUR	**575.30 EUR**	**55 %**
25	2,703.11 EUR	**1,169.47 EUR**	**57 %**

Cumulative savings





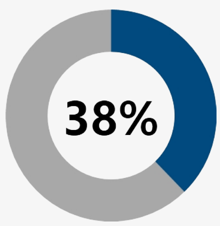
Details

Investment costs	**7,500.00 EUR**
Grant amount	**---**
Net present value	**2,975.84 EUR**
Annual return (IRR)	**11.8 %**
Amortization time	**8.8 a**

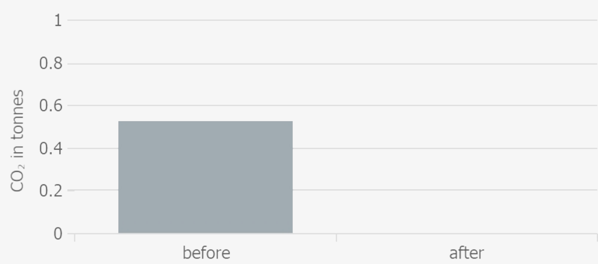
Energy	before	after	Savings
Total electrical energy consumption	3,487.00 kWh	**8,214.19 kWh**	**-136 %**
Total fuel energy consumption	5,172.00 kWh	**0.00 kWh**	**100 %**
Self-consumption		**3,101.51 kWh**	
Grid feed-in		**4,705.29 kWh**	

Renewable energies share

Self-sufficiency



CO_2 emissions



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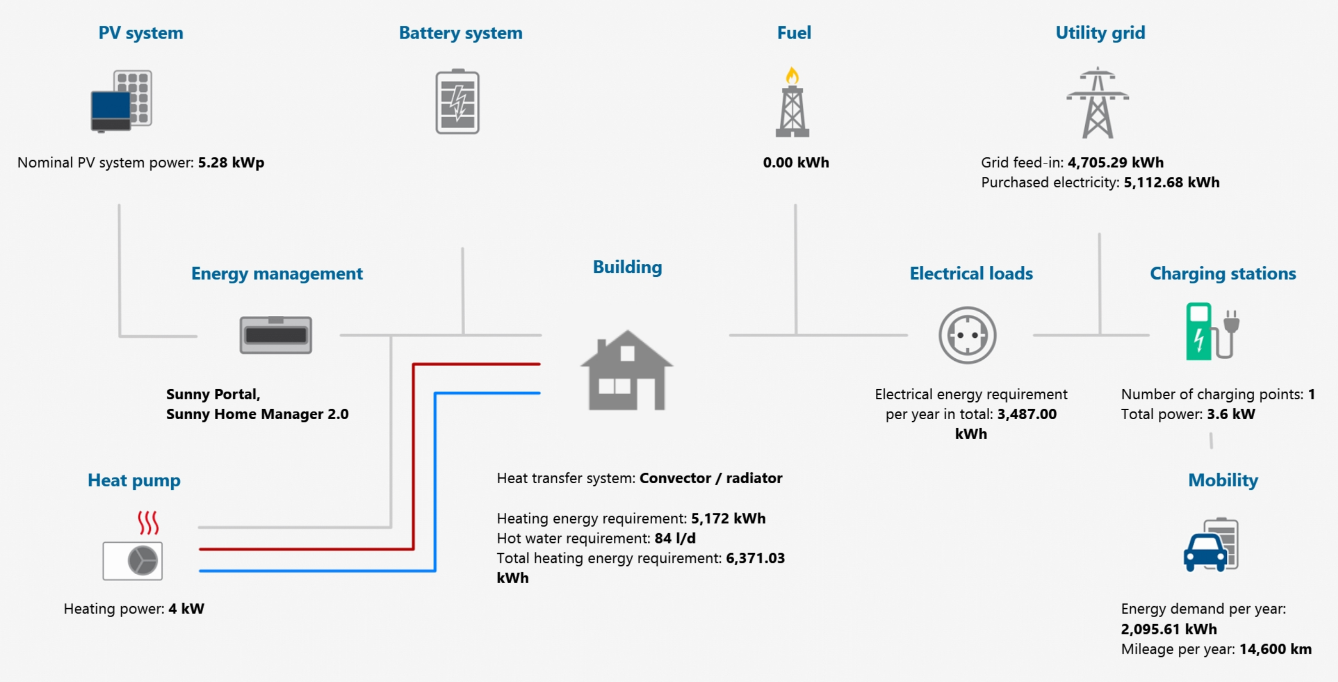
Energy system

Project name: Energy Management

Project number:

Location: Spain / Barcelona

Energy system schematic



Key figures

Energetic (annual values)		**Economics**	
Total electrical energy consumption:	8,214.19 kWh	Investment costs:	7,500.00 EUR
Electrical energy generated:	7,806.80 kWh	Total savings:	20,006.67 EUR
Self-consumption:	3,101.51 kWh	Amortization time:	8.8 a
Self-consumption quota:	39.7 %	Annual return (IRR):	11.8 %
Self-sufficiency quota:	37.8 %	Relative energy cost savings:	56.7 %
Solar fraction:	65 %	Electricity purchase costs:	20,975.01 EUR
Percentage of purchased energy savings:	60.2 %	Energy purchase costs:	20,975.01 EUR

PV design data

Total number of PV modules:	16	AC active power:	5.00 kW
Peak power:	5.28 kWp	Active power ratio:	94.7 %
Number of PV inverters:	1	Energy usability factor:	100 %
Nominal AC power of the PV inverters:	5.00 kW	Unbalanced load:	5.00 kVA

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Inverter designs

Project: Energy Management
Project number:

Subproject Subproject 1

Location: Spain / Barcelona
Ambient temperature:
Annual extreme low temperature: -1 °C
Average high Temperature: 24 °C
Annual extreme high temperature: 33 °C

1 x SMA SB5.0-1AV-41 (PV system section 1)

Peak power:	5.28 kWp
Total number of PV modules:	16
Number of PV inverters:	1
Max. DC power (cos φ = 1):	5.25 kW
Max. AC active power (cos φ = 1):	5.00 kW
Grid voltage:	230V (230V / 400V)
Nominal power ratio:	99 %
Dimensioning factor:	105.6 %
Displacement power factor cos φ:	1
Full load hours:	1604.6 h

SMA SB5.0-1AV-41

PV design data

Input A: Area 1 (South)
8 x Sharp ND-AH330H (09/2018), Azimuth angle: 0 °, Tilt angle: 20 °, Mounting type: Roof

Input B: Area 1 (South)
8 x Sharp ND-AH330H (09/2018), Azimuth angle: 0 °, Tilt angle: 20 °, Mounting type: Roof

	Input A:	Input B:
Number of strings:	1	1
PV modules:	8	8
Peak power (input):	2.64 kWp	2.64 kWp
Typical PV voltage:	✔ 275 V	✔ 275 V
Min. PV voltage:	257 V	257 V
Min. DC voltage (Grid voltage 230 V):	100 V	100 V
Max. PV voltage:	✔ 401 V	✔ 401 V
Max. DC voltage:	600 V	600 V
Max. MPP current of PV array:	✔ 8.7 A	✔ 8.7 A
Max. operating input current per MPPT:	15 A	15 A
Max. input short-circuit current per MPPT:	20 A	20 A
Photovoltaic Output Circuit Current:	✔ 9.3 A	✔ 9.3 A

PV/Inverter compatible

Cable sizing

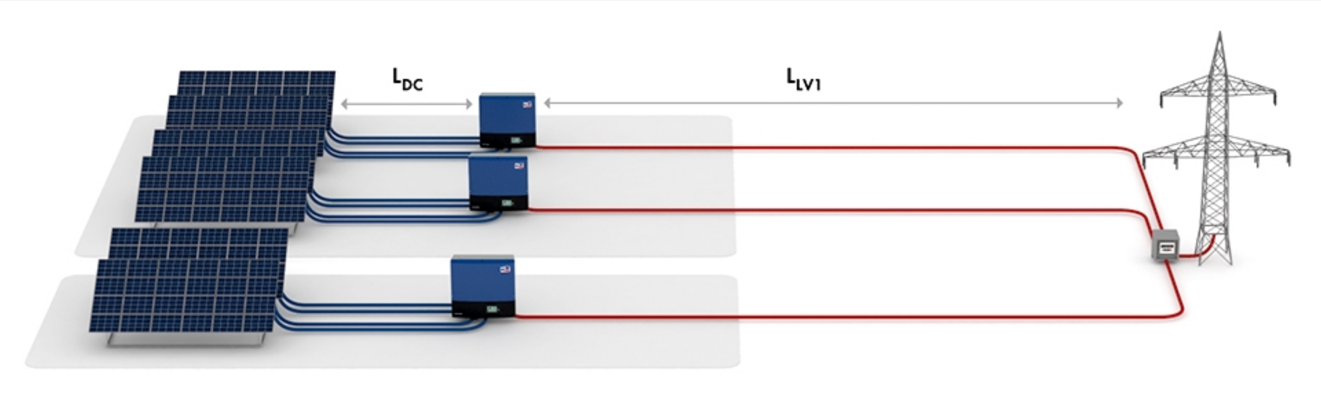
Project name: Energy Management
Project number:

Location: Spain / Barcelona

Overview

	DC	LV	Total
Power loss at nominal operation	14.75 W	40.64 W	55.39 W
Rel. power loss at rated nominal operation	0.28 %	0.81 %	1.09 %
Total cable length	40.00 m	10.00 m	50.00 m
Cable cross-sections	4 mm²	4 mm²	4 mm²

Graphic



DC cables

		Cable material	Single length	Cross section	Voltage drop	Rel. power loss
Subproject 1						
1 x SMA SB5. 0-1AV-41 PV system section 1	A	Copper	10.00 m	4 mm²	796.4 mV	0.28 %
	B	Copper	10.00 m	4 mm²	796.4 mV	0.28 %

Cables LV1

	Cable material	Single length	Cross section	Cable resistance	Rel. power loss
Subproject 1					
1 x SMA SB5. 0-1AV-41 PV system section 1	Copper	10.00 m	4 mm²	R: 86.000 mΩ XL: 1.500 mΩ	0.81 %

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Design energy management

Project name: Energy Management
Project number:

Location: Spain / Barcelona

PV system	System Monitoring	
Subproject 1	**Within the PV system**	**External**
1 x SMA SB5.0-1AV-41 PV system section 1	**Sunny Home Manager 2.0** The control center with integrated measuring system for smart energy management	**Sunny Portal** Internet portal for monitoring PV systems and for the visualization and presentation of PV system data

Information

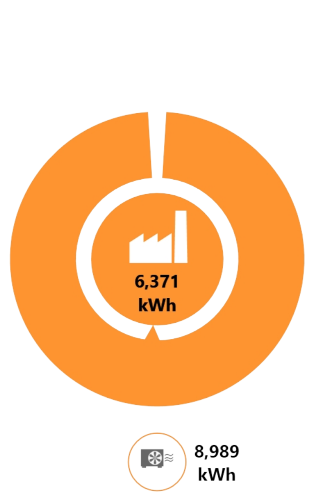
Sunny Home Manager 2.0	For the implementation of the storage management and the limitation of the active power feed-in, the internal measuring system of the Sunny Home Manager 2.0 for measuring the grid feed-in and purchased electricity, must have been connected and configured (see planning guidelines "SMA Smart Home").

Results energy

Project name: Energy Management
Project number:

Location: Spain / Barcelona

Energy balance (annual values)



Results (annual values)

Entire system	**before**	**after**
Total energy consumption	10,754.61 kWh	14,585.23 kWh
Renewable energies share	---	100.0 %
Generated renewable energy		14,171.04 kWh
Total purchased energy	12,850.22 kWh	5,112.68 kWh
CO_2 emissions	0.52 t	0.00 t
CO_2 reduction		100 %
Percentage of purchased energy savings		60.2 %
Utility grid		
Grid feed-in		4,705.29 kWh
Purchased electricity	5,582.61 kWh	5,112.68 kWh
Purchased electricity savings		8.4 %
Electricity		
Total energy requirement	3,487.00 kWh	8,214.19 kWh
Total electrical energy consumption	3,487.00 kWh	8,214.19 kWh
Electrical energy generated		7,806.80 kWh
Self-consumption		3,101.51 kWh
Self-consumption quota		39.7 %
Self-sufficiency quota		37.8 %
Max. purchased electricity power	12.46 kW	9.80 kW
Reduction of the purchased power peak		2.66 kW
Utilization time	448 h	522 h
CO_2 emissions	0.00 t	0.00 t
CO_2 reduction		0 %

Generated renewable energy		7,806.80 kWh
Renewable energies share	100.0 %	100.0 %
Fuel		
Total fuel energy consumption	5,172.00 kWh	0.00 kWh
Fuel savings		100 %
CO_2 emissions	---	0.00 t
CO_2 reduction		100 %
Thermal		
Total heating energy requirement	5,172.00 kWh	6,371.03 kWh
Heating energy generated		8,989.21 kWh
Generated renewable energy		6,364.24 kWh
Renewable energies share	---	100.0 %
Mobility		
Mileage		14,600 km
Power consumption		2,095.61 kWh
Power consumption grid		726.03 kWh
Solar fraction		65 %
CO_2 emissions	0.52 t	0.00 t
Number of unplanned charges		0
Total energy of all unplanned charges		0.00 kWh
Internally charged energy		2,095.61 kWh
Charging speed		100 %
Total charging duration		583.0 h
Building		
Heating energy requirement		5,171.87 kWh
Energy consumption heating element		7,207.49 kWh
Hot water energy requirement		1,199.16 kWh
Energy consumption hot water		1,781.72 kWh
Electrical loads		
Electrical energy requirement of the load profiles	3,487.00 kWh	3,487.00 kWh
Total energy requirement	3,487.00 kWh	8,214.19 kWh
PV system		
Electrical energy generated		7,806.80 kWh
Specific yield		1479 kWh/kWp
Grid feed-in		4,705.29 kWh
Self-consumption		3,101.51 kWh
Self-consumption quota		39.7 %
Self-sufficiency quota		37.8 %
Heat pump		
Electricity and fuel consumption		2,624.97 kWh
Heating energy generated		8,989.21 kWh
Annual performance factor		3.42

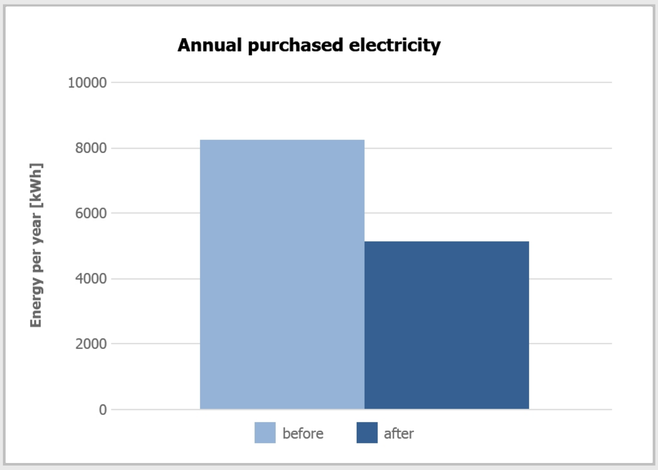
The displayed results are approximate values to give a general indication to users of possible operating results. The results are determined mathematically. The actual operating results will be dictated significantly by the actual climatic conditions, the actual efficiency, the system components' operating conditions and the individual consumption behavior and can deviate from the calculated results. SMA Solar Technology AG therefore assumes no liability in the event of deviations between the calculated and actual operating results.

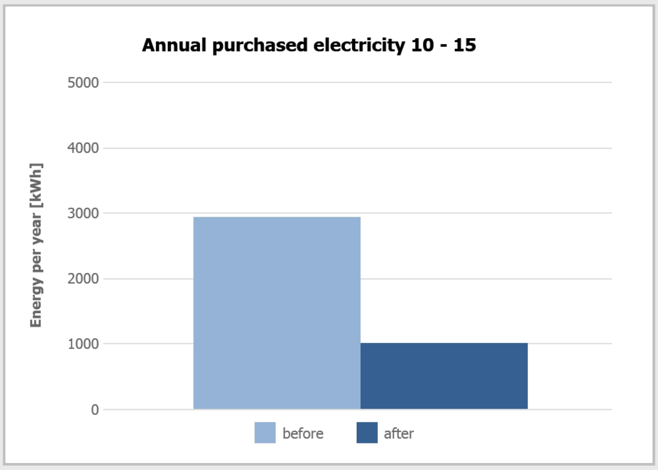
Load analysis

Project: Energy Management
Project number:

Purchased electricity

Electrical energy drawn from the utility grid per year is shown.

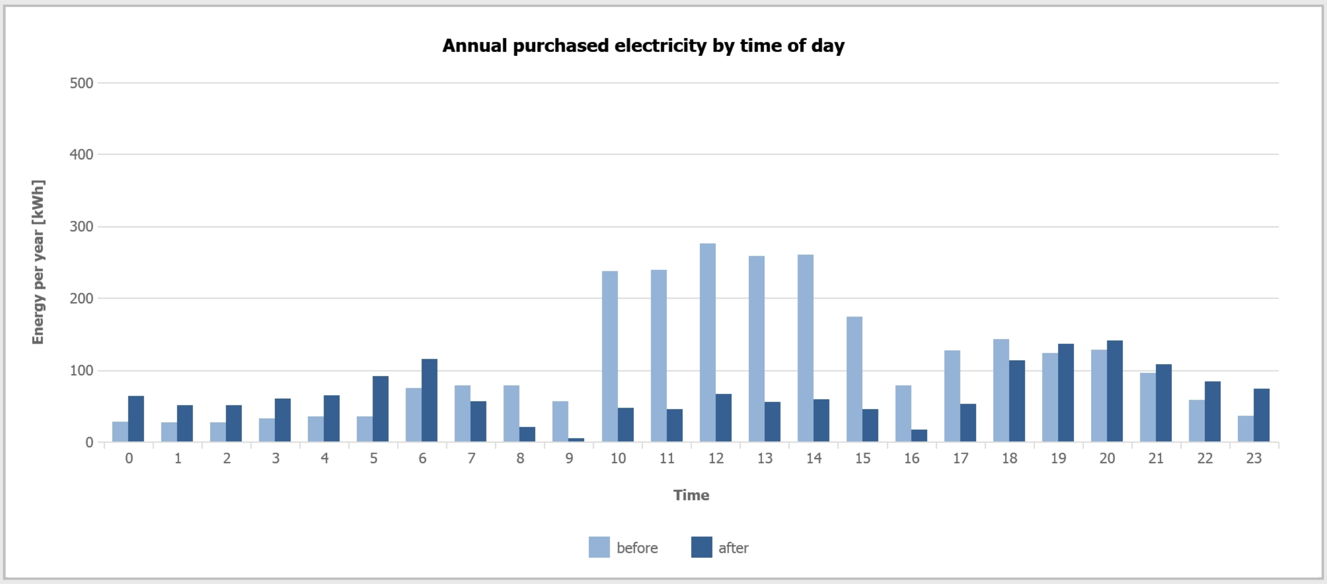




	Annual purchased electricity	Annual purchased electricity 10 - 15
before	8,214 kWh	2,929 kWh
after	5,113 kWh	1,003 kWh

Purchased electricity / time of day

Electrical energy drawn from the utility grid depending on the time of day is shown.

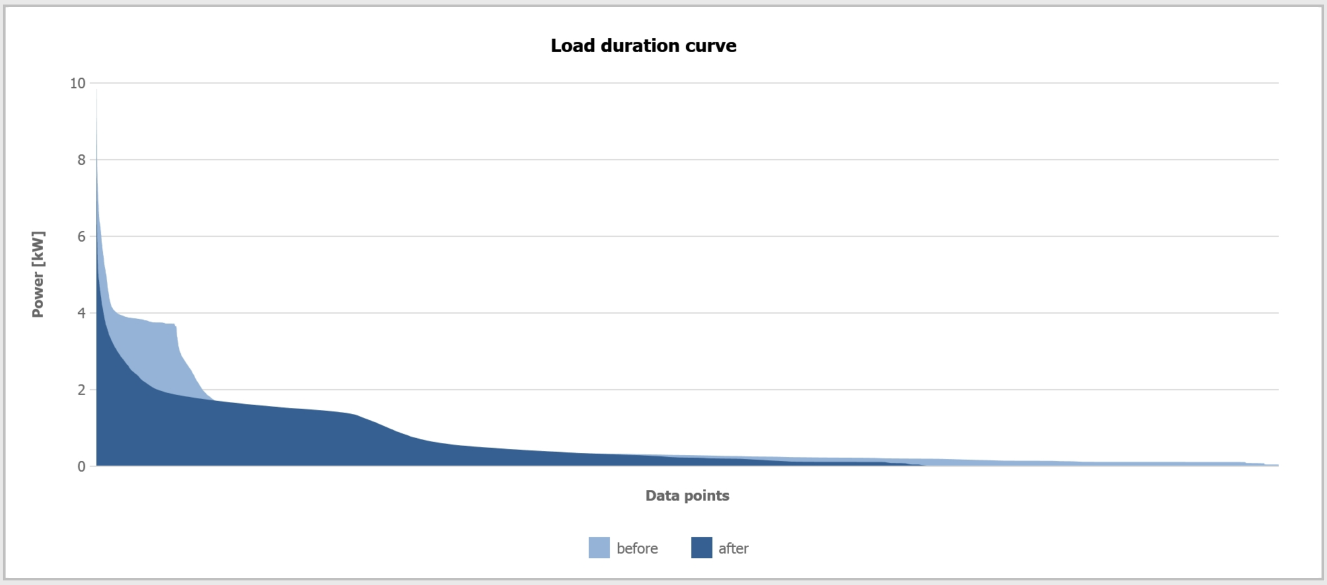


	Annual purchased electricity	April - September
before	8,214 kWh	2,692 kWh
after	5,113 kWh	1,608 kWh

Load analysis

Load duration curve

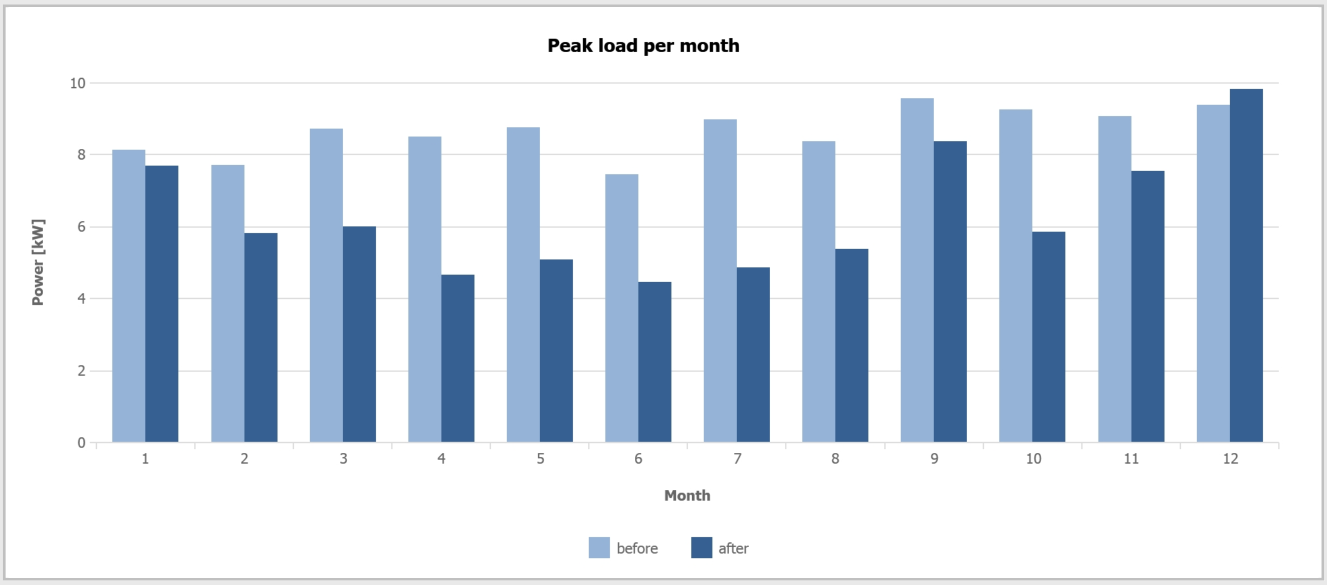
The diagram shows the power drawn from the utility grid as a load duration curve (load profile characteristic curve). The power values for a year are sorted by size. In particular, the diagram provides information on the frequency of the peak load, minimum load, and basic load.



	before	after
Power values above the load limit	---	--- (---)
Maximum power	9.538 kW	9.801 kW
Purchased electricity above the load limit	---	---
Total purchased electricity	8,214 kWh	5,113 kWh

Peak load

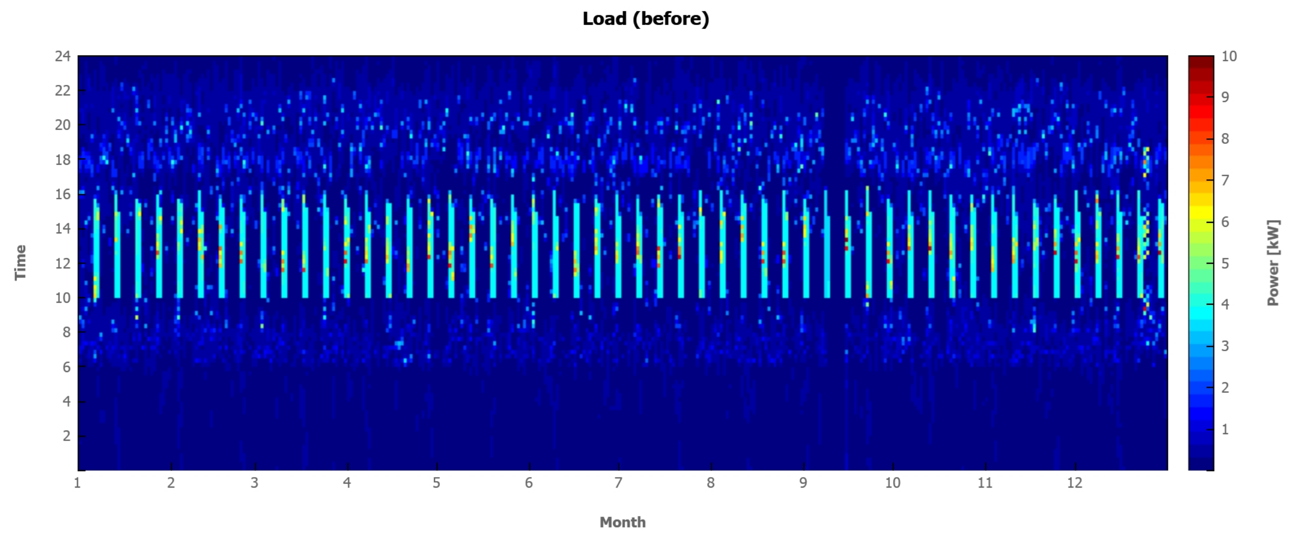
The maximum power per month drawn from the utility grid is shown, the so-called peak load. This peak load is used in some electricity tariffs as the basis for monthly billing.

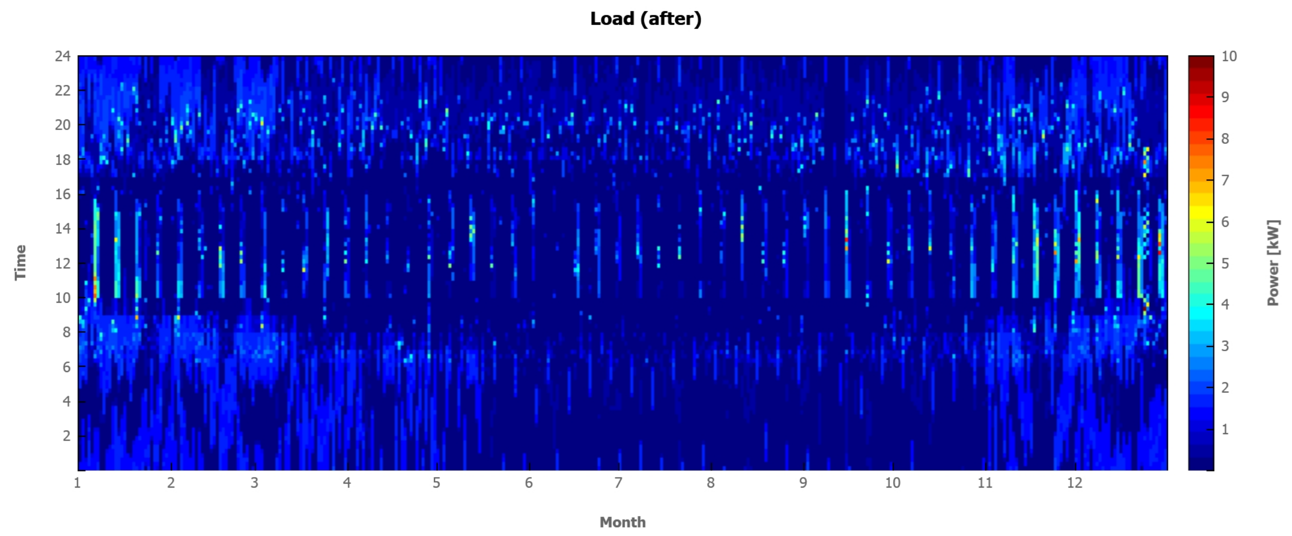


Load analysis

Power chart / load

The power values of one year depending on the time of day (vertical) and date (horizontal) are represented in this so-called heatmap.





The displayed results are estimated values which are derived mathematically. SMA Solar Technology AG accepts no liability for the actual self-consumption which may deviate from the values displayed here. The potential self-consumption essentially depends on individual load patterns, which may deviate from the load profile on which the calculation is based.

Profitability: settings

Project name: Energy Management
Project number:

Location: Spain / Barcelona

General

The currency is **EUR**

The analysis period of profitability is **25 Years**

The electric current purchasing tariff is **100% Renewable Lucera**

The inflation rate is **3.00 %**

The interest rate is **---**

PV system

The annual fixed costs are **0.00 %** of the investment costs

The service life is **25 Years**

The price change factor is **0 %**

The feed-in tariff for electric current is **PVPC excedentes 2.0**

The grant amount is **---**

The equity ratio is **100 %**

Selected type of credit: **None**

The credit period is **0 Years**

The redemption-free period is **0 Years**

The annual interest rate is **0.0 %**

Heat pump

The annual fixed costs are **0.00 %** of the investment costs

The service life is **25 Years**

The price change factor is **0 %**

The grant amount is **---**

The equity ratio is **100 %**

Selected type of credit: **None**

The credit period is **0 Years**

The redemption-free period is **0 Years**

The annual interest rate is **0.0 %**

Charging stations

The annual fixed costs are **0.00 %** of the investment costs

The service life is **25 Years**

The price change factor is **0 %**

The grant amount is **---**

The equity ratio is **100 %**

Selected type of credit: **None**

The credit period is **0 Years**

The redemption-free period is **0 Years**

The annual interest rate is **0.0 %**

The displayed results are approximate values to give a general indication to users of possible operating results. The results are determined mathematically. The actual operating results will be dictated significantly by the actual climatic conditions, the actual efficiency, the system components' operating conditions and the individual consumption behavior and can deviate from the calculated results. SMA Solar Technology AG therefore assumes no liability in the event of deviations between the calculated and actual operating results.

Results profitability

Project name: Energy Management
Project number:

Location: Spain / Barcelona

Profitability

Electricity costs in the first year

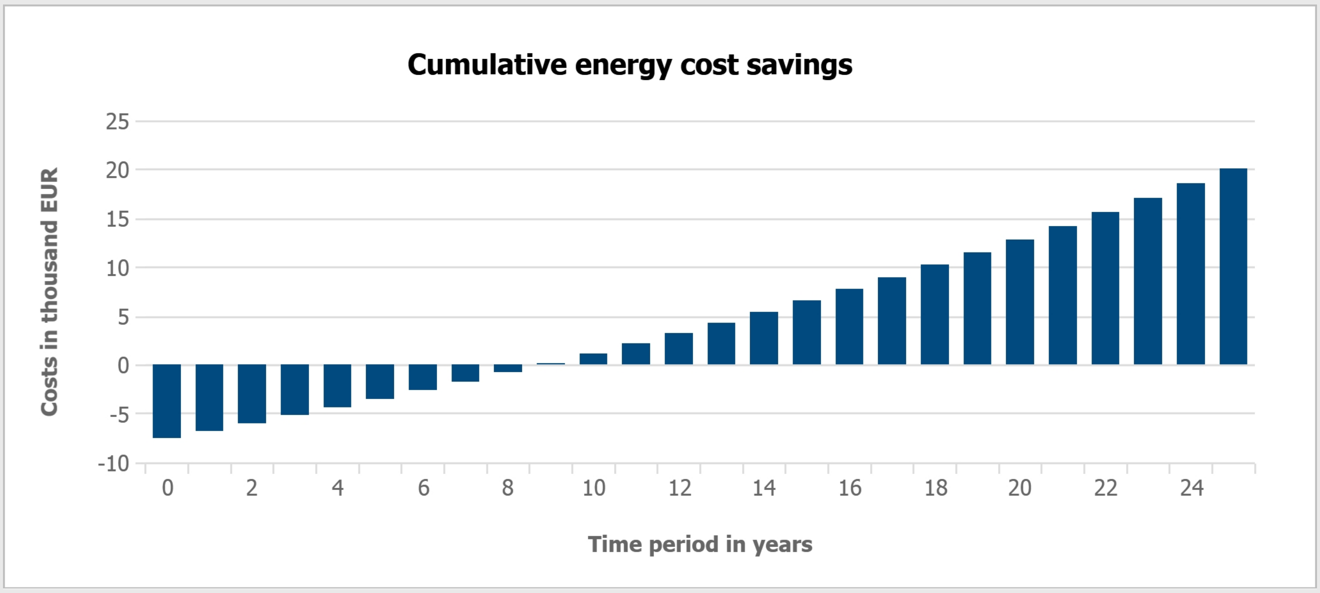
before
982.10 EUR/a

after
575.30 EUR/a

Fuel costs in the first year

before
308.92 EUR/a

after
0.00 EUR/a



Results

Entire system	before	after
Investment costs		7,500.00 EUR
Total energy supply costs		28,475.01 EUR
Total savings		20,006.67 EUR
Energy production costs		0.0426 EUR/kWh
Net present value		2,975.84 EUR
Amortization time		8.8 a
Amortization time (discounted)		14.5 a
Annual return (IRR)		11.8 %
Operating costs		10.00 EUR
Debt capital		---
Energy purchase costs	48,481.68 EUR	20,975.01 EUR
Residual value		0.00 EUR
Energy cost savings		27,506.67 EUR
Relative energy cost savings		56.7 %
Grant amount		---
Utility grid		
Electricity purchase costs	36,880.66 EUR	20,975.01 EUR

Specific electricity purchase costs	0.28164 EUR/kWh	0.11252 EUR/kWh
Feed-in tariff		0.00 EUR
Fuel		
Fuel costs	11,601.02 EUR	0.00 EUR
Avoided fuel costs		11,601.02 EUR
Thermal		
Heating costs	11,601.02 EUR	0.00 EUR
Specific heating costs	0.05 EUR/kWh	0.00 EUR/kWh
Heating cost savings		11,601.02 EUR
Relative heating cost savings		100 %
Mobility		
Energy costs	39.19 EUR	7,296.76 EUR
Relative energy costs	0.01 EUR/100 km	1.37 EUR/100 km
Savings		-7,257.57 EUR
PV system		
Investment costs		7,500.00 EUR
Specific investment costs		1,420.45 EUR/kWp
Energy production costs		0.0937 EUR/kWh
Operating costs		10.00 EUR
Residual value		0.00 EUR
Debt capital		---
Feed-in tariff		0.00 EUR
Grant amount		---
Heat pump		
Investment costs		0.00 EUR
Specific investment costs		0.00 EUR/kW
Energy production costs		0.0000 EUR/kWh
Operating costs		0.00 EUR
Residual value		0.00 EUR
Debt capital		---
Grant amount		---
Charging stations		
Yield from vehicle charge		0.00 EUR
Costs from vehicle charge		0.00 EUR
Investment costs		0.00 EUR
Operating costs		0.00 EUR
Debt capital		---
Grant amount		---
Residual value		0.00 EUR

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Project: **Energy Management**

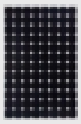
Project number: ---

Location: Spain / Barcelona

Grid voltage: 230V (230V / 400V)

System overview

PV arrays



16 x Sharp ND-AH330H (09/2018) (Area 1 (South))

Azimuth angle: 0 °, Tilt angle: 20 °, Mounting type: Roof, Peak power: 5.28 kWp

PV inverter

1 x SMA SB5.0-1AV-41

Battery system

SMA Sunny Boy Storage 5.0-10

+ Battery 1: BYD, Battery-Box H6.4 (6.40 kWh)

Energy management

Sunny Home Manager 2.0

Sunny Portal

Notes:

Signature

*Important: The yield values displayed are estimates. They are determined mathematically. SMA Solar Technology AG accepts no responsibility for the real yield value which can deviate from the yield values displayed here. Reasons for deviations are various external conditions, such as soiling of the PV modules or fluctuations in the efficiency of the PV modules.

Your energy system at a glance

Project: Energy Management
Project number: ---
Location: Location: Spain / Barcelona
Date: 6/2/2020

Created with Sunny Design 5.0.1.R

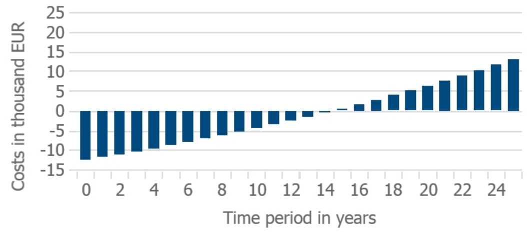
Total savings after 25 year(s)

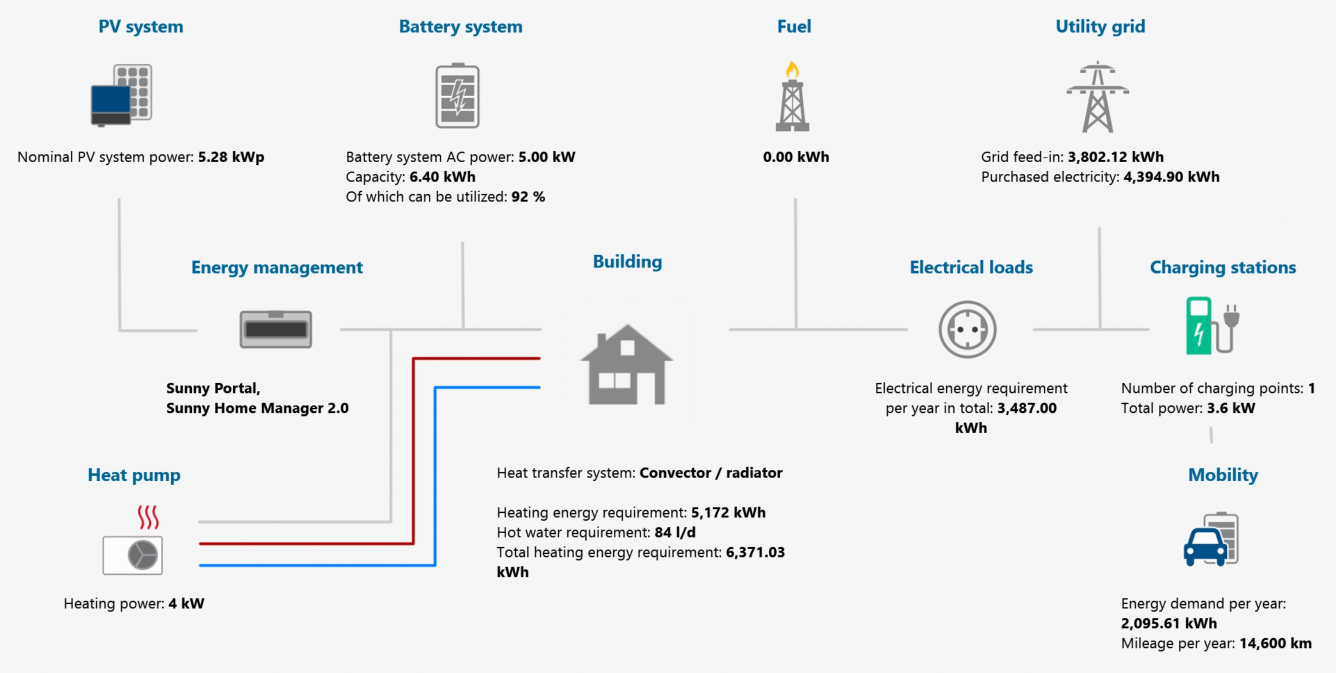
13,094.63 EUR

Energy purchase costs

Year	before	after	Savings
1	1,050.09 EUR	**379.58 EUR**	**64 %**
25	2,198.65 EUR	**771.62 EUR**	**65 %**

Cumulative savings





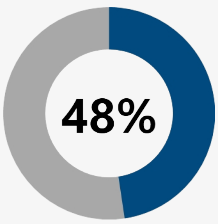
Details

Investment costs	**12,500.00 EUR**
Grant amount	**---**
Net present value	**-2,752.35 EUR**
Annual return (IRR)	**5.7 %**
Amortization time	**14.5 a**

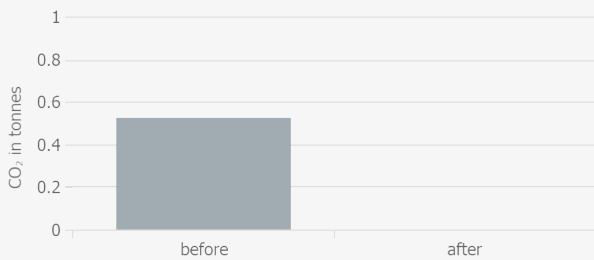
Energy	before	after	Savings
Total electrical energy consumption	3,487.00 kWh	**8,405.51 kWh**	**-141 %**
Total fuel energy consumption	5,172.00 kWh	**0.00 kWh**	**100 %**
Self-consumption		**4,005.79 kWh**	
Grid feed-in		**3,802.12 kWh**	

Renewable energies share

Self-sufficiency



CO_2 emissions



*Important: The yield values displayed are estimates. They are determined mathematically. SMA Solar Technology AG accepts no responsibility for the real yield value which can deviate from the yield values displayed here. Reasons for deviations are various external conditions, such as soiling of the PV modules or fluctuations in the efficiency of the PV modules.

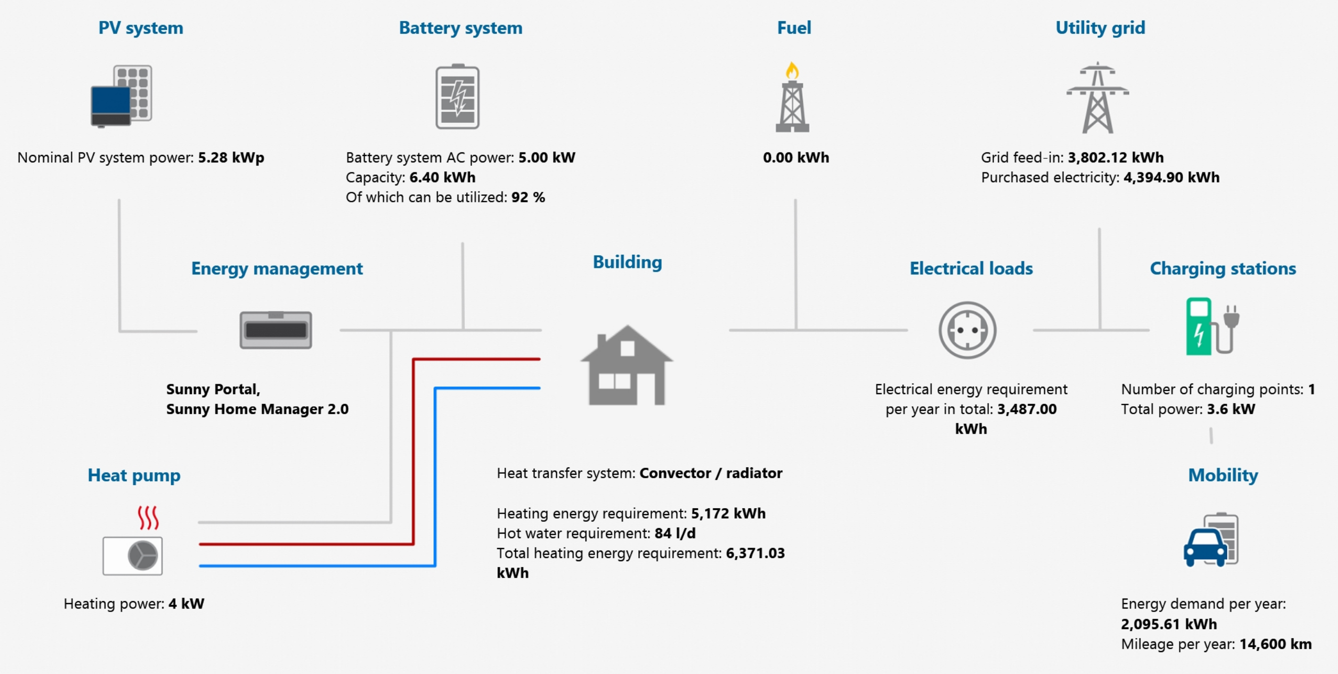
Energy system

Project name: Energy Management

Project number:

Location: Spain / Barcelona

Energy system schematic



Key figures

Energetic (annual values)		Economics	
Total electrical energy consumption:	8,405.51 kWh	Investment costs:	12,500.00 EUR
Electrical energy generated:	7,806.80 kWh	Total savings:	13,094.63 EUR
Self-consumption:	4,005.79 kWh	Amortization time:	14.5 a
Self-consumption quota:	51.3 %	Annual return (IRR):	5.7 %
Self-sufficiency quota:	47.7 %	Relative energy cost savings:	64.9 %
Solar fraction:	0 %	Electricity purchase costs:	13,839.35 EUR
Percentage of purchased energy savings:	65.8 %	Energy purchase costs:	13,839.35 EUR

PV design data

Total number of PV modules:	16	AC active power:	5.00 kW
Peak power:	5.28 kWp	Active power ratio:	94.7 %
Number of PV inverters:	1	Energy usability factor:	100 %
Nominal AC power of the PV inverters:	5.00 kW	Unbalanced load:	5.00 kVA

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Inverter designs

Project: Energy Management
Project number:

Subproject Subproject 1

Location: Spain / Barcelona
Ambient temperature:
Annual extreme low temperature: -1 °C
Average high Temperature: 24 °C
Annual extreme high temperature: 33 °C

1 x SMA SB5.0-1AV-41 (PV system section 1)

Peak power:	5.28 kWp
Total number of PV modules:	16
Number of PV inverters:	1
Max. DC power (cos φ = 1):	5.25 kW
Max. AC active power (cos φ = 1):	5.00 kW
Grid voltage:	230V (230V / 400V)
Nominal power ratio:	99 %
Dimensioning factor:	105.6 %
Displacement power factor cos φ:	1
Full load hours:	1604.6 h

SMA SB5.0-1AV-41

PV design data

Input A: Area 1 (South)
8 x Sharp ND-AH330H (09/2018), Azimuth angle: 0 °, Tilt angle: 20 °, Mounting type: Roof

Input B: Area 1 (South)
8 x Sharp ND-AH330H (09/2018), Azimuth angle: 0 °, Tilt angle: 20 °, Mounting type: Roof

	Input A:	Input B:
Number of strings:	1	1
PV modules:	8	8
Peak power (input):	2.64 kWp	2.64 kWp
Typical PV voltage:	✓ 275 V	✓ 275 V
Min. PV voltage:	257 V	257 V
Min. DC voltage (Grid voltage 230 V):	100 V	100 V
Max. PV voltage:	✓ 401 V	✓ 401 V
Max. DC voltage:	600 V	600 V
Max. MPP current of PV array:	✓ 8.7 A	✓ 8.7 A
Max. operating input current per MPPT:	15 A	15 A
Max. input short-circuit current per MPPT:	20 A	20 A
Photovoltaic Output Circuit Current:	✓ 9.3 A	✓ 9.3 A

PV/Inverter compatible

Design battery system

Project name: Energy Management

Project number:

Location: Spain / Barcelona

Battery system

SMA Sunny Boy Storage 5.0-10

For increased self-consumption for single-family homes with high-voltage lithium battery.
Battery voltage range: 100 V - 550 V

Batteries: BYD, Battery-Box H6.4 (6.40 kWh)

Capacity: 6.40 kWh **Of which can be utilized:** 92 %

To implement increased self-consumption, you need either an SMA Energy Meter or a Sunny Home Manager.

Design data

Application:	Self-consumption increase
Batteries:	Lithium
Total nominal capacity:	6.40 kWh
!'strSystemStorageUseable!:	5.89 kWh
Intermediately stored electrical energy:	2,148.34 kWh
Annual nominal energy throughputs of the battery:	335.7

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Cable sizing

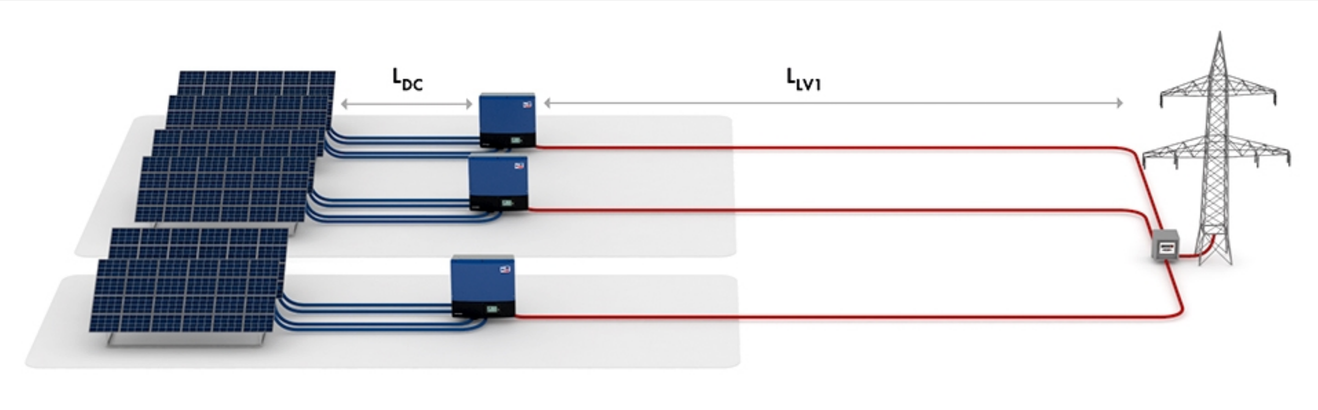
Project name: Energy Management | **Location: Spain / Barcelona**

Project number:

Overview

	DC	LV	Total
Power loss at nominal operation	14.75 W	40.64 W	55.39 W
Rel. power loss at rated nominal operation	0.28 %	0.81 %	1.09 %
Total cable length	40.00 m	10.00 m	50.00 m
Cable cross-sections	4 mm²	4 mm²	4 mm²

Graphic



DC cables

		Cable material	Single length	Cross section	Voltage drop	Rel. power loss
Subproject 1						
1 x SMA SB5. 0-1AV-41 PV system section 1	A	Copper	10.00 m	4 mm²	796.4 mV	0.28 %
	B	Copper	10.00 m	4 mm²	796.4 mV	0.28 %

Cables LV1

	Cable material	Single length	Cross section	Cable resistance	Rel. power loss
Subproject 1					
1 x SMA SB5. 0-1AV-41 PV system section 1	Copper	10.00 m	4 mm²	R: 86.000 mΩ XL: 1.500 mΩ	0.81 %

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Design energy management

Project name: Energy Management
Project number:

Location: Spain / Barcelona

PV system	System Monitoring	
Subproject 1	**Within the PV system**	**External**
1 x SMA SB5.0-1AV-41 PV system section 1	**Sunny Home Manager 2.0** The control center with integrated measuring system for smart energy management	**Sunny Portal** Internet portal for monitoring PV systems and for the visualization and presentation of PV system data

Information	
Sunny Home Manager 2.0	For the implementation of the storage management and the limitation of the active power feed-in, the internal measuring system of the Sunny Home Manager 2.0 for measuring the grid feed-in and purchased electricity, must have been connected and configured (see planning guidelines "SMA Smart Home").

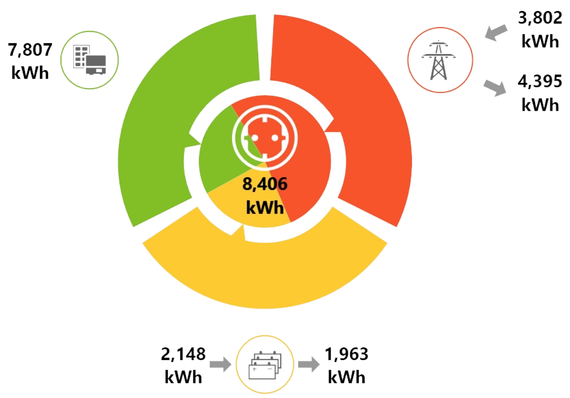
Results energy

Project name: Energy Management
Project number:

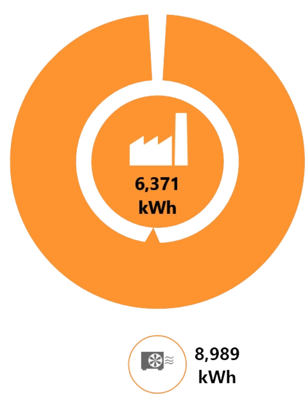
Location: Spain / Barcelona

Energy balance (annual values)

Electricity



Thermal



Results (annual values)

Entire system	before	after
Total energy consumption	10,754.61 kWh	14,585.23 kWh
Renewable energies share	---	100.0 %
Generated renewable energy		14,171.04 kWh
Total purchased energy	12,850.22 kWh	4,394.90 kWh
CO_2 emissions	0.52 t	0.00 t
CO_2 reduction		100 %
Percentage of purchased energy savings		65.8 %
Utility grid		
Grid feed-in		3,802.12 kWh
Purchased electricity	5,582.61 kWh	4,394.90 kWh
Purchased electricity savings		21.3 %
Electricity		
Total energy requirement	3,487.00 kWh	8,214.20 kWh
Total electrical energy consumption	3,487.00 kWh	8,405.51 kWh
Electrical energy generated		7,806.80 kWh
Self-consumption		4,005.79 kWh
Self-consumption quota		51.3 %
Self-sufficiency quota		47.7 %
Max. purchased electricity power	7.66 kW	6.46 kW
Reduction of the purchased power peak		1.20 kW
Utilization time	729 h	681 h
CO_2 emissions	0.00 t	0.00 t
CO_2 reduction		0 %

Generated renewable energy		7,806.80 kWh
Renewable energies share	100.0 %	100.0 %
Fuel		
Total fuel energy consumption	5,172.00 kWh	0.00 kWh
Fuel savings		100 %
CO_2 emissions	---	0.00 t
CO_2 reduction		100 %
Thermal		
Total heating energy requirement	5,172.00 kWh	6,371.03 kWh
Heating energy generated		8,989.21 kWh
Generated renewable energy		6,364.24 kWh
Renewable energies share	---	100.0 %
Mobility		
Mileage		14,600 km
Power consumption		2,095.61 kWh
Power consumption grid		2,095.61 kWh
Solar fraction		0 %
CO_2 emissions	0.52 t	0.00 t
Number of unplanned charges		0
Total energy of all unplanned charges		0.00 kWh
Internally charged energy		2,095.61 kWh
Charging speed		100 %
Total charging duration		587.8 h
Building		
Heating energy requirement		5,171.87 kWh
Energy consumption heating element		7,207.49 kWh
Hot water energy requirement		1,199.16 kWh
Energy consumption hot water		1,781.72 kWh
Electrical loads		
Electrical energy requirement of the load profiles	3,487.00 kWh	3,487.00 kWh
Total energy requirement	3,487.00 kWh	8,214.20 kWh
PV system		
Electrical energy generated		7,806.80 kWh
Specific yield		1479 kWh/kWp
Grid feed-in		3,801.01 kWh
Self-consumption		4,005.79 kWh
Self-consumption quota		51.3 %
Self-sufficiency quota		47.7 %
Battery system		
Intermediately stored electrical energy		2,148.34 kWh
Annual nominal energy throughputs of the battery		335.7
Electrical energy withdrawn		1,962.95 kWh
Heat pump		
Electricity and fuel consumption		2,624.97 kWh
Heating energy generated		8,989.21 kWh
Annual performance factor		3.42

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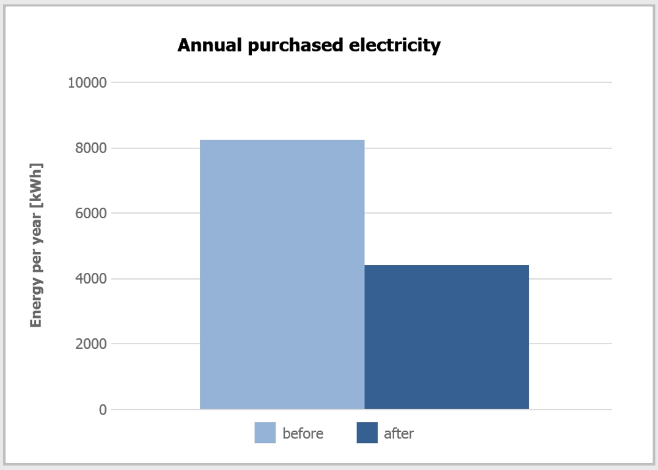
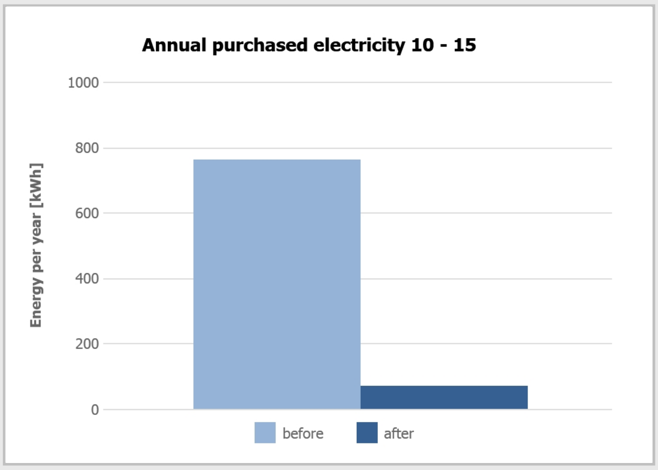
Load analysis

Project: Energy Management
Project number:

Purchased electricity

Electrical energy drawn from the utility grid per year is shown.

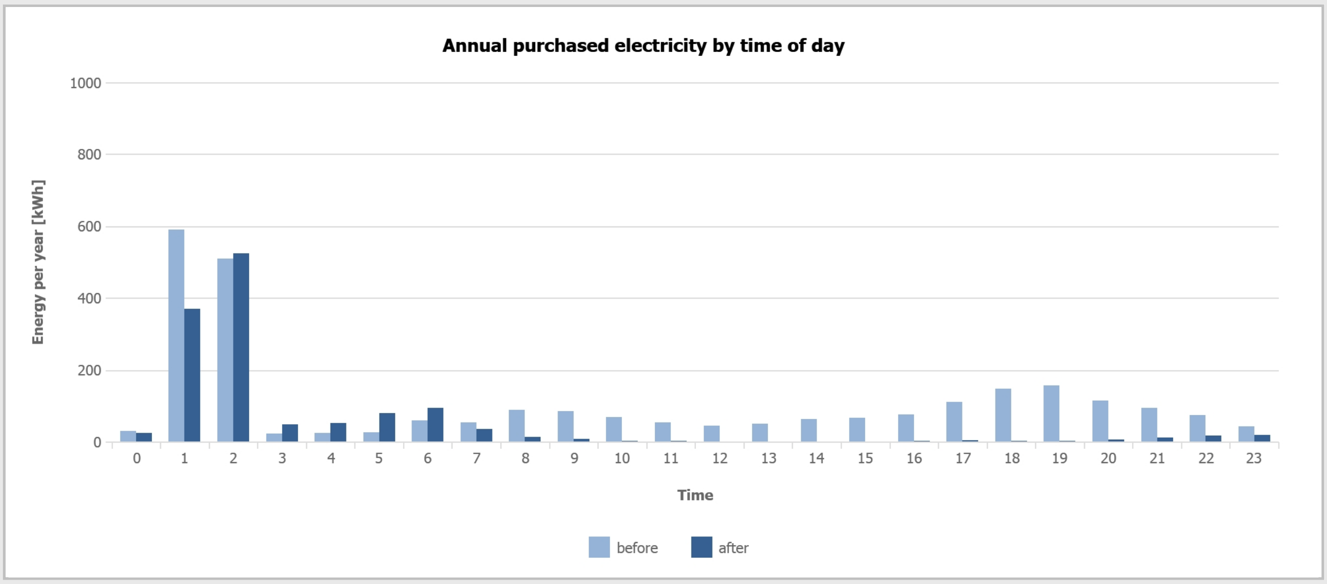




	Annual purchased electricity	Annual purchased electricity 10 - 15
before	8,214 kWh	761 kWh
after	4,395 kWh	70 kWh

Purchased electricity / time of day

Electrical energy drawn from the utility grid depending on the time of day is shown.

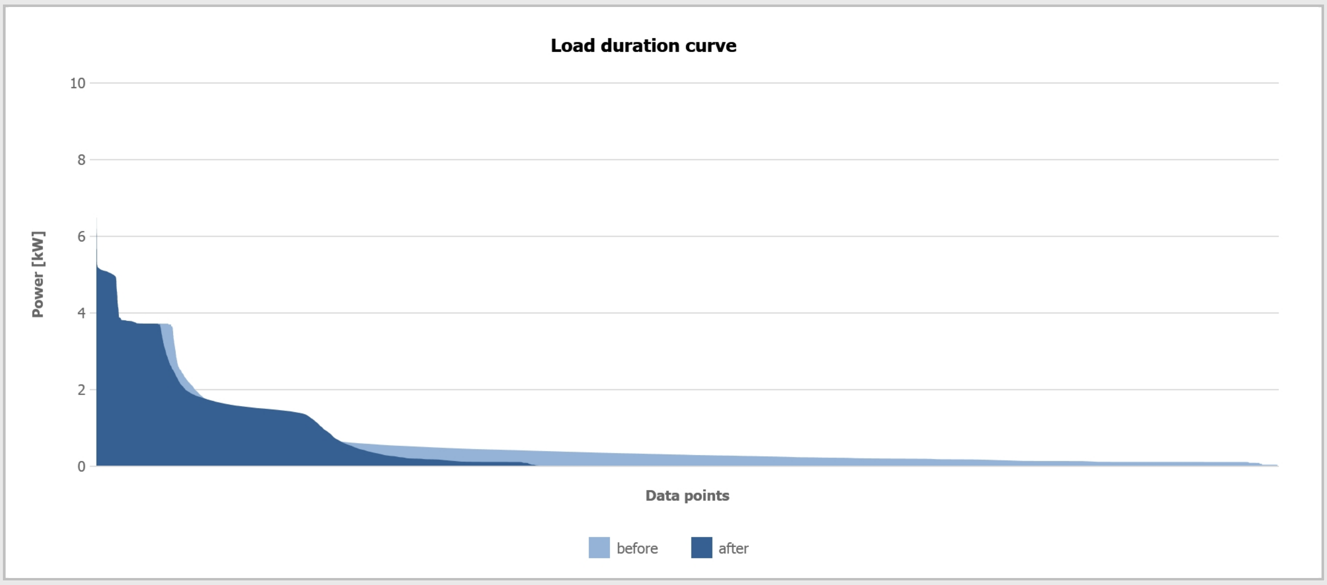


	Annual purchased electricity	April - September
before	8,214 kWh	2,632 kWh
after	4,395 kWh	1,295 kWh

Load analysis

Load duration curve

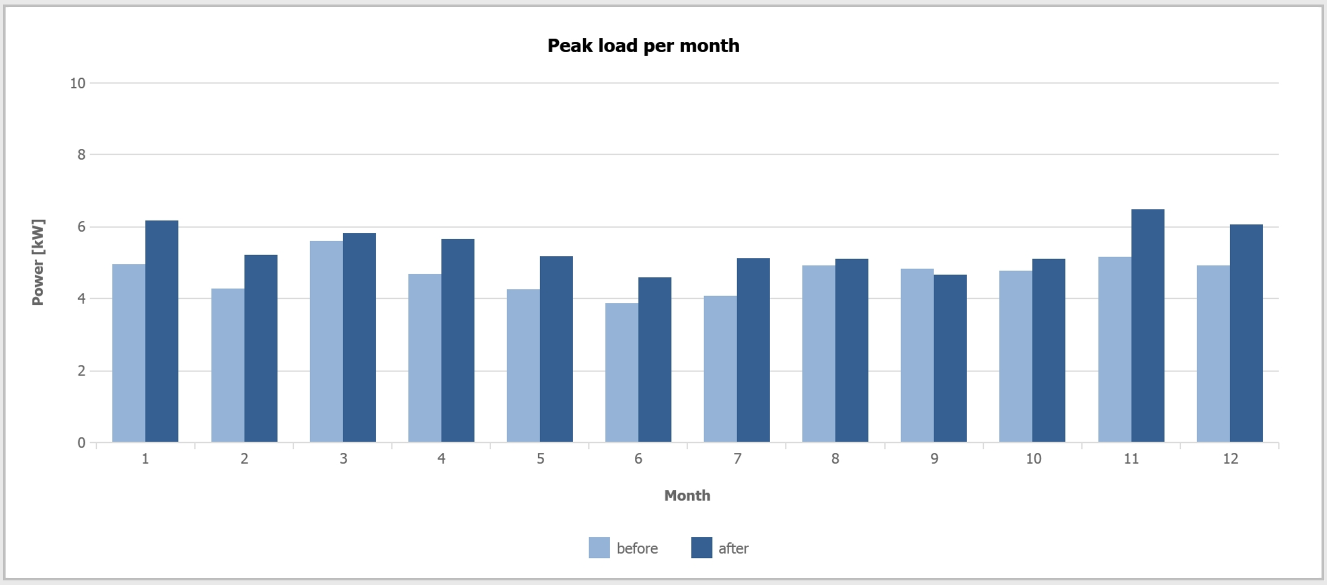
The diagram shows the power drawn from the utility grid as a load duration curve (load profile characteristic curve). The power values for a year are sorted by size. In particular, the diagram provides information on the frequency of the peak load, minimum load, and basic load.



	before	after
Power values above the load limit	---	--- (---)
Maximum power	5.579 kW	6.457 kW
Purchased electricity above the load limit	---	---
Total purchased electricity	8,214 kWh	4,395 kWh

Peak load

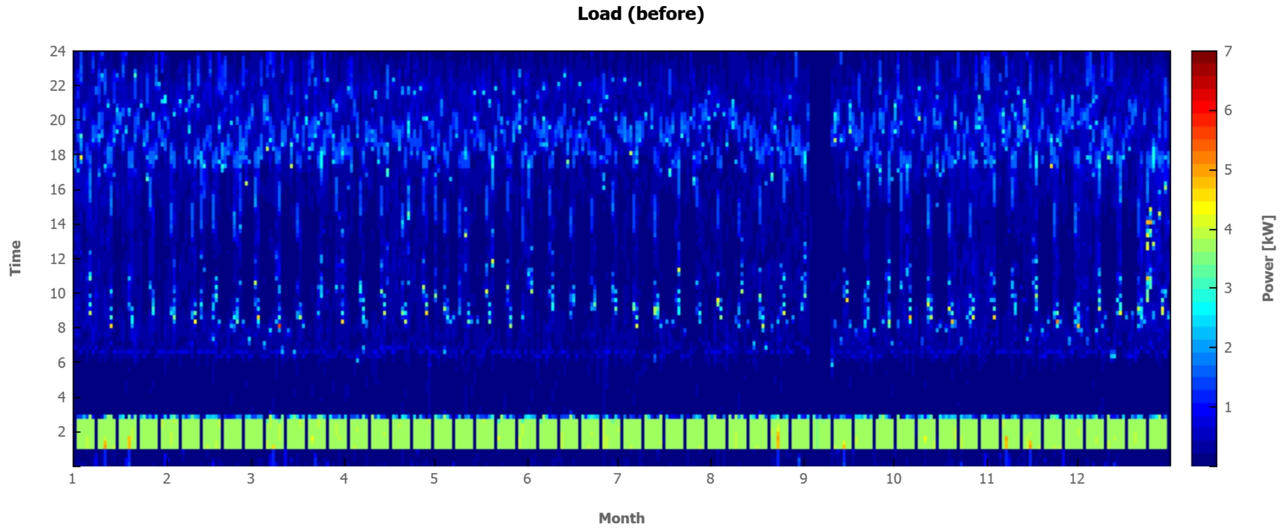
The maximum power per month drawn from the utility grid is shown, the so-called peak load. This peak load is used in some electricity tariffs as the basis for monthly billing.

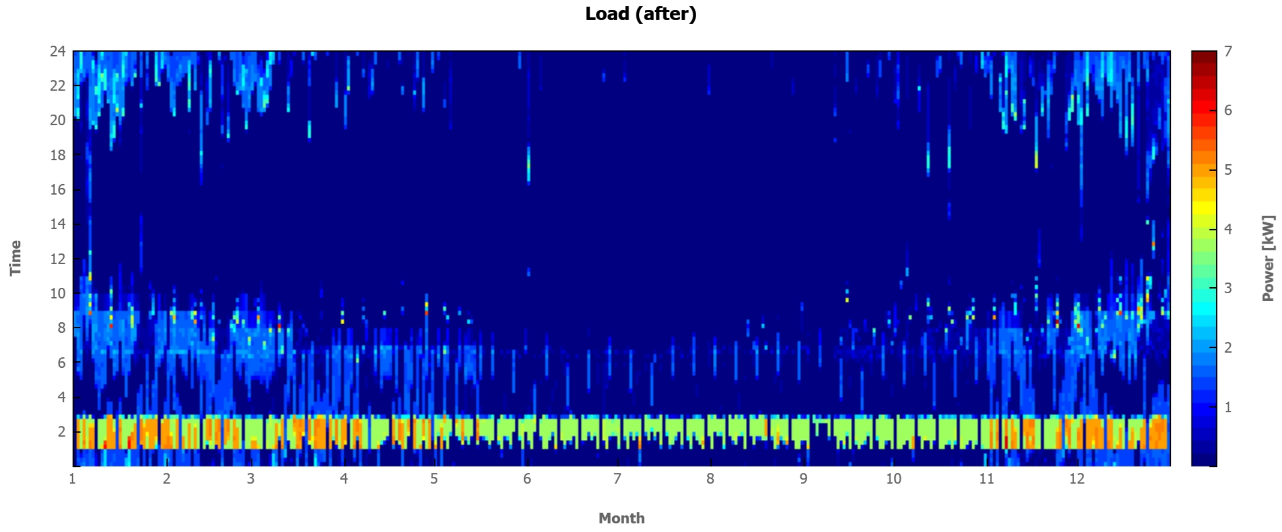


Load analysis

Power chart / load

The power values of one year depending on the time of day (vertical) and date (horizontal) are represented in this so-called heatmap.





The displayed results are estimated values which are derived mathematically. SMA Solar Technology AG accepts no liability for the actual self-consumption which may deviate from the values displayed here. The potential self-consumption essentially depends on individual load patterns, which may deviate from the load profile on which the calculation is based.

Profitability: settings

Project name: Energy Management
Project number:

Location: Spain / Barcelona

General

The currency is **EUR**
The analysis period of profitability is **25 Years**
The electric current purchasing tariff is **100% Renewable Lucera**

The inflation rate is **3.00 %**
The interest rate is **---**

PV system

The annual fixed costs are **0.00 %** of the investment costs
The service life is **25 Years**
The price change factor is **0 %**
The feed-in tariff for electric current is **PVPC excedentes 2.0**
The grant amount is **---**

The equity ratio is **100 %**
Selected type of credit: **None**
The credit period is **0 Years**
The redemption-free period is **0 Years**
The annual interest rate is **0.0 %**

Battery system

Battery inverter
The annual fixed costs are **0.00 %** of the investment costs
The service life is **25 Years**
The price change factor is **0 %**

Battery
The annual fixed costs are **0.00 %** of the investment costs
The service life is **25 Years**
The price change factor is **0 %**
The grant amount is **---**

The equity ratio is **100 %**
Selected type of credit: **None**
The credit period is **0 Years**
The redemption-free period is **0 Years**
The annual interest rate is **0.0 %**

Heat pump

The annual fixed costs are **0.00 %** of the investment costs
The service life is **25 Years**
The price change factor is **0 %**
The grant amount is **---**

The equity ratio is **100 %**
Selected type of credit: **None**
The credit period is **0 Years**
The redemption-free period is **0 Years**
The annual interest rate is **0.0 %**

Charging stations

The annual fixed costs are **0.00 %** of the investment costs
The service life is **25 Years**
The price change factor is **0 %**
The grant amount is **---**

The equity ratio is **100 %**
Selected type of credit: **None**
The credit period is **0 Years**
The redemption-free period is **0 Years**
The annual interest rate is **0.0 %**

Results profitability

Project name: Energy Management
Project number:

Location: Spain / Barcelona

Profitability

Electricity costs in the first year

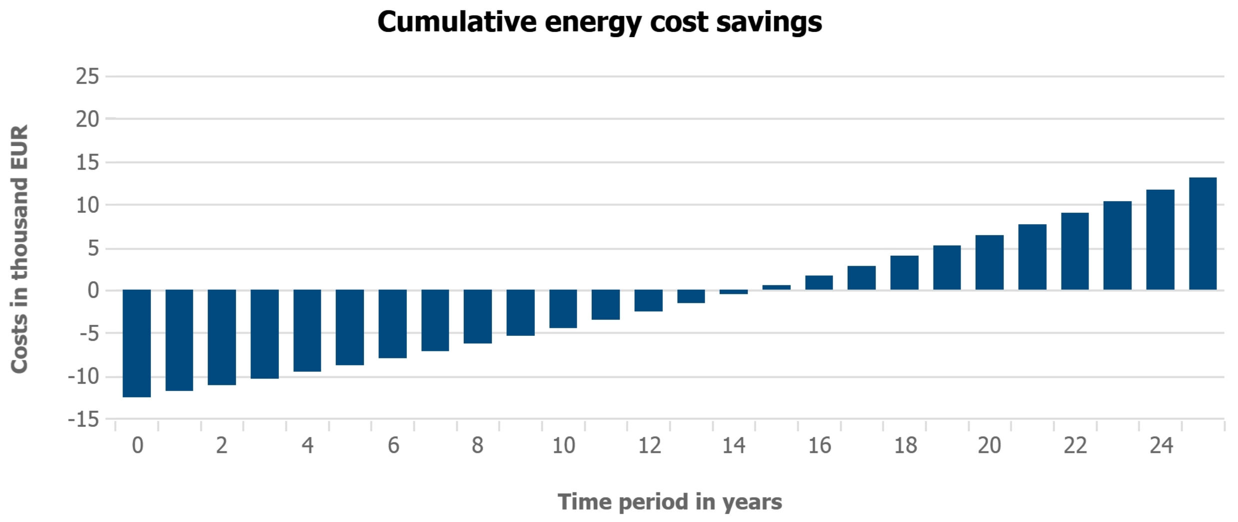
before
741.16 EUR/a

after
379.58 EUR/a

Fuel costs in the first year

before
308.92 EUR/a

after
0.00 EUR/a



Results

Entire system	before	after
Investment costs		12,500.00 EUR
Total energy supply costs		26,339.35 EUR
Total savings		13,094.63 EUR
Energy production costs		0.0710 EUR/kWh
Net present value		-2,752.35 EUR
Amortization time		14.5 a
Amortization time (discounted)		---
Annual return (IRR)		5.7 %
Operating costs		10.00 EUR
Debt capital		---
Energy purchase costs	39,433.98 EUR	13,839.35 EUR
Residual value		0.00 EUR
Energy cost savings		25,594.63 EUR
Relative energy cost savings		64.9 %
Grant amount		---
Utility grid		
Electricity purchase costs	27,832.96 EUR	13,839.35 EUR

Specific electricity purchase costs	0.21255 EUR/kWh	0.08637 EUR/kWh
Feed-in tariff		0.00 EUR
Fuel		
Fuel costs	11,601.02 EUR	0.00 EUR
Avoided fuel costs		11,601.02 EUR
Thermal		
Heating costs	11,601.02 EUR	0.00 EUR
Specific heating costs	0.05 EUR/kWh	0.00 EUR/kWh
Heating cost savings		11,601.02 EUR
Relative heating cost savings		100 %
Mobility		
Energy costs	39.19 EUR	10,422.64 EUR
Relative energy costs	0.01 EUR/100 km	1.96 EUR/100 km
Savings		-10,383.45 EUR
PV system		
Investment costs		7,500.00 EUR
Specific investment costs		1,420.45 EUR/kWp
Energy production costs		0.0937 EUR/kWh
Operating costs		10.00 EUR
Residual value		0.00 EUR
Debt capital		---
Feed-in tariff		0.00 EUR
Grant amount		---
Battery system		
Investment costs		5,000.00 EUR
Operating costs		0.00 EUR
Residual value		0.00 EUR
Debt capital		---
Grant amount		---
Heat pump		
Investment costs		0.00 EUR
Specific investment costs		0.00 EUR/kW
Energy production costs		0.0000 EUR/kWh
Operating costs		0.00 EUR
Residual value		0.00 EUR
Debt capital		---
Grant amount		---
Charging stations		
Yield from vehicle charge		0.00 EUR
Costs from vehicle charge		0.00 EUR
Investment costs		0.00 EUR
Operating costs		0.00 EUR
Debt capital		---
Grant amount		---
Residual value		0.00 EUR

The displayed results are approximate values to give a general indication to users of possible operating results. The results are determined mathematically. The actual operating results will be dictated significantly by the actual climatic conditions, the actual efficiency, the system components' operating conditions and the individual consumption behavior and can deviate from the calculated results. SMA Solar Technology AG therefore assumes no liability in the event of deviations between the calculated and actual operating results.